The Space Encyclopaedia

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A Guide to Astronomy and Space Research

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New, revised Edition

NEW YORK
E. P. DUTTON & CO., INC.

Fourth Printing October 1965

LIBRARY OF CONGRESS CATALOG CARD NUMBER: 59-5818

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The Publishers' thanks are also due for material and information received from the following:

The Royal Society, Royal Astronomical Society, Air Ministry, Ministry of Supply, California Institute of Technology, Harvard University Observatory, Sperry Rand Corporation, Glenn Martin Company, Douglas Aircraft Corporation, Lockheed Aircraft Corporation, the British Interplanetary Society, World Data Centre C, and many others who have supplied photographs.

PREFACE

WHAT, it may be asked, can bring together in one book subjects as remote from each other as the study of extragalactic nebulae and the development of rocket motors? In our endeavour to break away from the Earth, no matter by how little or for how short a time, celestial mechanics and the astronomy of the solar system are united naturally with electronic and mechanical engineering; but the exploration of space would be of narrow significance if we did not look beyond our local adventure for some understanding of the Universe as a whole. This has been the guiding idea in the compilation of this book.

Words printed in **bold type** indicate those articles which it may be useful to consult for additional information.

The articles on Astronomy, Cosmology and Radio Astronomy, and those on Guided Missiles, Artificial Satellites and Rocketry, are recommended as general introductions to their respective subjects.

For individual missiles not listed under their own names, please refer to the table under **Missile.**

A

A-4. The German code number for the V–2 rocket bomb, from which the **Viking** rocket has been derived. The fuel was ethyl alcohol, and the oxidant liquid oxygen, which also served as coolant on its passage to the combustion chamber. It burnt nine tons of propellent in 69 seconds and developed a thrust of up to 70,000 lb., with a maximum speed at cut-off of 3,500 m.p.h.

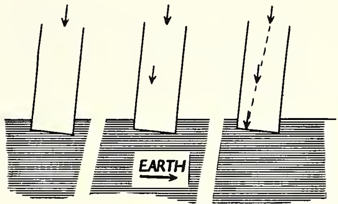
A9-A10 PROJECT. A German design of 1942 for a two-stage long-range surface-to-surface missile. The A-10 was to carry the A-9 component (itself an improved A-4) to a height of 15.2 miles, and the latter would then cover 2,500 miles in 35 minutes, using nitric acid and diesel oil as propellents. It was to be guided on to the target in its terminal glide. A-9 was successfully tested, but A-10 was still on the drawing-board at the end of the war.

THE A9-A10 DESIGN. The fins of the A-9 component were to fit into slots in A-10, leaving only the nose projecting at take-off.

Å. See **Angstrom Unit.**

ABERRATION OF LIGHT is responsible for a small apparent displacement of stars as seen by an observer moving with the Earth.

If a pellet is dropped down the middle of a vertical tube, and if the tube is moving sideways while the pellet is falling, the pellet will not fall along the centre line of the tube. To an observer moving with the tube, the pellet will appear to be slanting towards the wall of the tube. In the same way, light traversing a telescope is apparently deflected, since the telescope is moving with the Earth at nearly 20 miles per second while the light is travelling through it. This will affect the observed position of stars by up to 20″.5.



Three rays of light from a distant star enter a telescope along its mid-line. Moving at some 18 miles per second, the Earth carries the telescope across the line of sight, and the rays appear to be coming in from a direction which differs slightly from the true direction of the star.

The speed of light is reduced by about $\frac{1}{4}$ when it passes through water. In 1871 the English astronomer Airy filled a telescope with water to measure the effect on the aberration. Since the light would now take longer to traverse the telescope, the aberration should have been noticeably increased. Contrary to all expectation, it remained unchanged. This surprising result was incompatible with the old idea of the aether, and did not find its explanation until Einstein formulated his Theory of **Relativity,** for which it is still one of the most direct pieces of evidence.

ABSOLUTE TEMPERATURE is temperature expressed in degrees Kelvin (° K.) above **absolute zero.** A degree Kelvin equals a degree Centigrade in range, so that

$$\textit{absolute temp.} = \textit{Centigrade temp.} + 273.16$$

ABSOLUTE ZERO. The lowest possible temperature; it is the starting point of the absolute scale of temperature, and equals –273.16° C.

Cold is merely the absence of heat. Heat may be defined as the energy inherent in the *random* motion of the molecules in a substance. As a body cools, so this motion decreases, but some of it remains even in a body which 'feels' ice-cold to the touch. When there is *no* random molecular (or atomic) motion left, the body is at absolute zero.

Temperatures less than a millionth of a degree above absolute zero have been attained in the laboratory, but it can never be reached completely. Its precise value relative to the Centigrade scale is known from theoretical calculations.

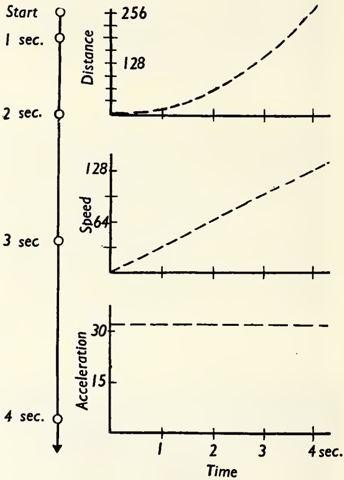
ABSORPTION, GALACTIC. See **Galactic Absorption.**

ABSORPTION SPECTRA. Spectra consisting of dark lines, dark bands or a dark continuum superposed on a bright background and caused by the absorption of light by a substance placed in front of a bright source. For example, the dark lines of the solar spectrum are produced by radiation from the deeper layers being absorbed in the cooler, outer layers of the Sun. See **Spectroscopy.**

ACCELERATION. Rate of change of velocity. A body which at one moment moves with a velocity of 10 miles per second, and which one second later moves at 12 miles per second, has undergone an acceleration of 2 miles per second per second, or 2 miles/sec.^{2}. If the velocity had decreased, the acceleration would be negative, i.e. it would be a *retardation.*

A body falling under the influence of gravity gathers speed, i.e. it is accelerated, and apart from air-resistance this acceleration is exactly the same for a light body as for a heavy one. Thus the effect of gravity may be expressed in terms of the acceleration it produces, usually in cm./sec.^{2} or feet/sec.^{2}.

In the case of gravity, acceleration is uniform (or linear) over a short distance. In other cases it may not be; e.g. a stone propelled by an ordinary catapult has maximum acceleration at the moment of release, when the accelerating force of the tension is greatest but the stone's speed is still zero; when the elastic is relaxed and the catapult has spent its driving force, the acceleration will have sunk to zero, and the speed will have reached its maximum.



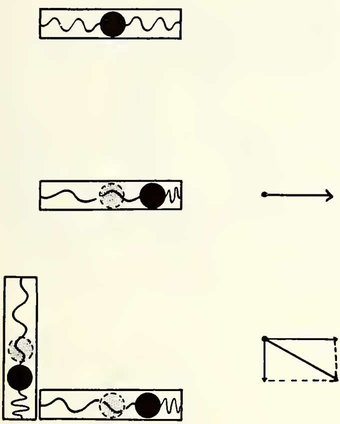
THREE GRAPHS for a body falling from rest near the surface of the Earth. *Bottom:* the acceleration due to gravity is constant at 32 feet per second^2. *Middle:* the speed of the falling body increases uniformly; it is plotted in feet per second. *Top:* the total distance fallen (in feet) is here plotted against time (in seconds); this graph should be compared with the diagram on the left, in which the falling body is seen in the positions it occupies after 1, 2, 3 and 4 seconds.

It must always be remembered that it requires just as much energy to accelerate a given body to a certain speed as to bring it to rest once it has attained that speed. In most everyday examples this energy is supplied by the action of the force of gravity, which slows down a stone that has been accelerated upwards, or by friction, which will slow down an object sliding on a horizontal surface. In the absence of such forces, a body once in

motion will continue to move in a straight line. The work that has to be done to stop it is equal to the body's kinetic energy, i.e. the product of its mass with half the square of its velocity. (See also **Energy** and **Gravity.**) (M.T.B.)

ACCELEROMETER. An instrument for measuring **acceleration.** It usually relies upon the fact that

force = mass × acceleration.



PRINCIPLE OF A SPRING ACCELEROMETER. *Top:* resting position. *Middle:* acceleration to the left. *Bottom:* acceleration to the upper left, resolved into vertical and horizontal components. The arrows show displacement of the weight (in the *opposite* sense to acceleration).

In its simplest form it is a pendulum free to swing in a certain direction. The angle which it assumes to the vertical is a measure of the acceleration in that direction. Entirely different forms have to be used in fast aircraft and missiles.

ACHILLES. One of the Trojan group of **Asteroids.** Diam. 150 miles.

ADIABATIC CHANGE. A change in matter not involving any transfer of heat. A thermally insulated mass of gas may be heated (or cooled) by compressing (or expanding) it adiabatically.

ADONIS. A small **asteroid** with a diameter of a few miles. Owing to the eccentricity of its orbit it has come quite close to the Earth ($1\frac{1}{2}$ million miles in 1936).

AERIA. An ochre-coloured 'desert' region on **Mars.**

AERIAL. See **Antenna.**

AEROBEE. A high altitude research rocket. It is simple in design; it contains no guiding equipment of any kind and depends entirely on arrow stability. It is launched with the aid of a solid-propellent booster from a 140 ft. launching tower which can be tilted.

AIR BREAK-UP. A method of recovery of instruments from a high-altitude rocket.

If a heavy, streamlined missile is allowed to fall to earth from a great height it can bury itself so deeply that recovery of instruments may be extremely difficult, and damage by the impact will be severe. This is sometimes avoided by firing a cartridge inside the missile by means of a time switch or radio signal while it is in mid-air, causing it to break up into separate sections. Those containing important instruments will now be of poor aerodynamic form and will therefore be greatly retarded by air resistance, so that together with parachutes a relatively gentle landing becomes possible.

AIRGLOW. Even when the Moon is not in the night sky perfect blackness of the sky is not obtained. Some of the remaining light (about $\frac{1}{6}$) comes from the stars and nebulae, and from interplanetary material reflecting the solar rays. But a large proportion of the total arises within the Earth's atmosphere itself. During the daytime the solar rays dissociate molecules and ionize atoms in the upper atmosphere. At night the energy absorbed by the processes is released, and some of it appears as visible light, thus giving rise to the airglow.

Airglow has been simulated by releasing nitric oxide gas or sodium vapour from rockets

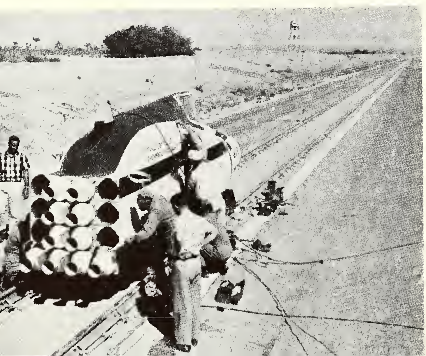
at varying heights and from the first Russian artificial planet at 71,000 miles. In each case a patch of light was observed which slowly spread and faded away. The observations gave information on winds at high altitudes, the nature of airglow, and the luminescence of comets, and allowed a visual check to be made on the position of the artificial planet at the time of release of vapour.

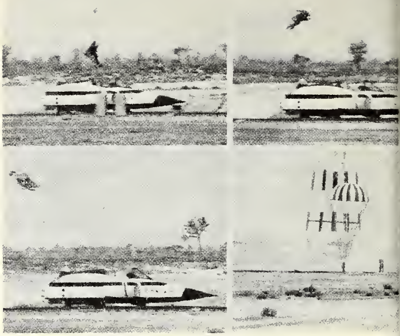
Airglow limits the faintest objects which can be photographed from terrestrial observatories, and this can be overcome only by establishing observatories beyond the atmosphere.

AIRLOCK. A system of airtight doors or other openings for transferring an object from a sealed air-filled space into space at very low pressure (or *vice versa*) with the minimum loss of air. The principle is the same as that of escape hatches or torpedo tubes in submarines. An object to be transferred to the outside is first placed in a small chamber which is sealed off from the main chamber before being opened to the vacuum. The process can also be reversed.

AIR RESISTANCE. The retarding force acting on a body moving through air. A more sophisticated term is *aerodynamic drag*. At low speeds the air flow past a moving object is *streamline*, i.e. the layers of air near the body slip smoothly over one another; at high speeds turbulence sets in and the air eddies past the object. Various factors combine to give the total air resistance: skin, form, interference, and wave drags.

A ROCKET–PROPELLED SLED used to test aircraft ejector seats. Up to sixteen rocket motors can be inserted in the rear. Sleds such as this have reached 1,100 m.p.h. At speeds of this order air resistance can cause serious injury unless special precautions are taken. (*U.S. Air Force photo.*)





Four stages in the operation of the ejector seat 'saving' the dummy pilot of the sled. In the last photograph the dummy is about to land by parachute. In other experiments, the 'pilot' and seat have been completely enclosed in an ejection capsule. (*U.S. Air Force photo.*)

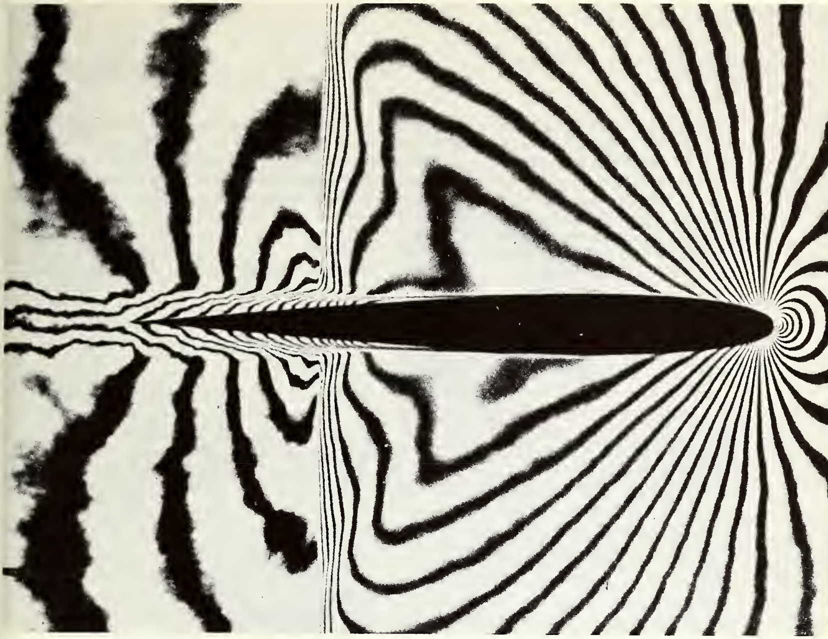
SKIN DRAG occurs because of the motion between different layers of air near the moving body; the air immediately in contact with the surface moves with the body. As the air resistance is much greater for turbulent than streamline flow, designers aim to preserve the latter as far as possible.

FORM DRAG is occasioned by variations of pressure round a moving body. An extreme case is that of a flat plate, where the pressure is greatly increased on the forward face and greatly reduced behind the plate. At speeds less than that of sound, form drag may be reduced by using an elongated shape with a rounded nose and pointed tail.

INTERFERENCE DRAG is caused by projections which disturb the air flow round the object, for instance the wings and tail of an aircraft. It is minimized by rounding all projections and interstices.

WAVE DRAG occurs at supersonic speeds. The air in front of a body moving faster than sound cannot get out of the way quickly enough, and is suddenly compressed when the object arrives; shock waves are formed at the front and back of the object.

The compression of air in shock waves



AIR FLOW AT HIGH SUBSONIC SPEED round a wing section in a wind tunnel – a picture taken at one millionth of a second. (*National Physical Laboratory*)

A wind-tunnel photograph showing shock waves in an air stream flowing past a model at about 2,000 m.p.h., and turbulence on either side of the tail.

leads to adiabatic heating, and friction in the air layers near a moving surface also generates heat. At sufficiently great speeds, the temperature of the surface of, say, an aircraft becomes high enough to cause the structural materials to **creep**, and ultimately melt. Stainless steel and titanium structures and surface refrigeration are being used in an effort to overcome this so-called 'heat barrier'.

ALBEDO. The fraction of the total incident sunlight which is reflected back in all directions by a planet, satellite or asteroid, or any part of their surfaces. Albedos observed astronomically may be compared with those of known substances measured in the laboratory, and can give valuable clues as to the nature of the surfaces of the celestial body. Some typical albedos are:

Moon	0.07
Mars	0.15
Venus	0.59
Asteroids	0.1 (appr.)

Thus the Moon reflects less than 1/14th of the total sunlight it receives, and must therefore have a fairly dark surface; Venus, with its atmosphere of dense white cloud, reflects

ALBEDO. The albedo of a planet can be markedly influenced by clouds; in this picture, the clouds reflect far more sunlight than either the mountain top or the ground below.

(*Fairchild Aerial Surveys*)

more than half. Artificial satellites in some cases are given shiny surfaces with a high albedo, and this assists visual tracking.

ALBERT. An **asteroid** (No. 719) with a diameter of about 3 miles. It has a very eccentric orbit, its perihelion being within 20 million miles of the Earth's orbit while its aphelion is nearly as far from the Sun as Jupiter.

ALCOR, or *The Test*, is a faint star in the **Great Bear** constellation. It lies close to the much brighter **Mizar,** with which it forms a binary system, and has for centuries been used as an eyesight test: a person who can distinguish it with the naked eye from Mizar has normal eyesight.

ALGOL (β Persei). An eclipsing double star. Its name means 'Demon Star', and its cyclic changes in magnitude were probably known to the Arab astronomers. During its 69-hour cycle it loses two-thirds of its brightness in 5 hours, and the change is easily observed with the naked eye. To astrologers it was the most ominous of all stars. See **Binary Star.**

ALGOL BINARY. A double star consisting, like **Algol,** of a **main sequence** star and a **subgiant** which eclipse each other. They were probably formed by splitting at a fairly recent time, but in that case it is hard to explain why the larger component should be the fainter. One interesting theory is that slightly uneven development of the two stars causes the larger and initially brighter one to deviate to the right of the main sequence; it expands until the other star is engulfed in it, loses material and so decreases in size without gaining in luminosity. Its central portion, still large, would then evolve naturally until it is once more distinct from its companion. (See **Hertzsprung - Russell Diagram** and **Binary Star.**)

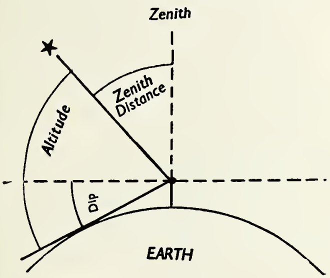
ALINDA. A small asteroid with an orbit similar to that of **Albert.**

ALPHA CENTAURI. A very bright multiple star in the constellation *Centaurus*. Its brightest component closely resembles the Sun. It is 4.3 light years away and the second-nearest star to the Earth, the only nearer star being a much fainter component of the same system called **Proxima Centauri.**

ALPHA PARTICLE. The nucleus of a helium atom, consisting of two protons and two neutrons, i.e. doubly ionized helium.

ALTITUDE. Height. In Astronomy, the angle between a star or object, the observer, and the point on the observer's horizon immediately below the star. It is often measured with a **sextant**, and has to be corrected for the dip of the horizon and atmospheric refraction to convert *observed* into *true* altitude.

True altitude + zenith distance = 90°.



AMALTHEA. The unofficial name of one of **Jupiter's** moons. It is near enough to its planet to be deformed by the enormous gravitational strain, and is being drawn towards Jupiter at a rate of one or two inches a year. This will cause its destruction in about seventy million years. Its diameter is some 150 miles.

AMERICAN ROCKET SOCIETY. Founded in 1930 as the 'American Interplanetary Society', it has devoted itself to the development of propulsion methods. Its monthly journal *Jet Propulsion* maintains a high technical level. *Address:* Northampton Street, Easton, Pa., U.S.A.

AMMONIA, NH_3, is a colourless, pungent and strongly alkaline gas. Its melting point is −78° C., and boiling point −33° C. at normal pressure. It is poisonous except in low concentration. It forms a large part of the atmosphere of **Jupiter**, where it occurs both as fine crystals and as vapour, and exists in the solid form on **Uranus** and **Neptune**.

Ordinary 'household ammonia' is a solution of the gas in water.

AMOR. An **asteroid** with a diameter of ten miles. Its fairly eccentric orbit can bring it within 10 million miles of the Earth.

ANDROMEDA NEBULA (Messier 31). This great spiral galaxy in many ways resembles our own Milky Way system, and belongs to the same local group of about 20 galaxies. It is visible to the naked eye as a faint blur in the constellation *Andromeda*; but if the human eye were greatly more sensitive, then even without magnification this nebula would be one of the most splendid objects in the sky, with an apparent diameter six times that of the Sun.

The distance of M 31 is 700,000 parsecs, and its diameter over 30,000 parsecs. The spiral arms contain **super-giants, Cepheids,** frequent **novae** (about two a month), diffuse and dark **nebulae,** and open clusters. The nucleus has only recently been resolved into individual stars; it is by far the brightest part of the galaxy.

The spiral rotates, but not uniformly: the centre turns like a wheel, but the more outlying portions lag behind, so that the arms are becoming more 'tightly wound'. They already describe two to three turns about the centre.

Like our own galaxy, M 31 is surrounded by about two hundred **globular clusters,** each containing perhaps a hundred thousand stars similar to those in the spiral itself. It also has at least two elliptical companion galaxies, Messier 32 superposed on the spiral arm, and NGC 205 a small distance away.

ANDROMEDIDS. A **meteor** shower associated with the comet **Biela,** and hence also called *Bielids.* Showers of Andromedids were recorded in 1741 and have been traced with some probability to A.D. 524. There were great storms from this centre in 1872 and 1885, and the occurrence of these showers appeared at the time to have some connection with the disruption of the comet, which had actually been witnessed in 1846 (see **Comet).** Showers of Andromedids in 1798, 1830 and 1838, however, must have radiated from a point on the orbit in front of the comet. The orbit suffers a rapid regression of the **nodes,** as a result of which the shower occurs one day earlier every 7 years, At present it falls on November 14, but shows little activity.

THE GREAT ANDROMEDA GALAXY Messier 31, and its two elliptical satellites.
(*Ritchey and Pease*)

ANGSTROM UNIT, abbreviated A. or Å, is a very small unit of length employed mainly for the measurement of the **wavelength** of light. It is equal to one hundred-millionth of a centimetre.

ANGULAR MOMENTUM. This is a quantity which is defined for any body which is rotating, or travelling in a curved path, around some axis; it is the product of the mass of the body and the rate of its rotation. A very important physical law is that of the *conservation of angular momentum:* this states that in any system which is not acted upon by external forces, the total angular momentum remains unchanged. The law holds regardless of what takes place within the system.

One of its consequences is that if a spinning body contracts it must, in the absence of other forces, increase its rate of spin.

ANGULAR VELOCITY. The rate of change of the direction of a moving point as measured from a point at rest. It is usually expressed in **radians** per second, but can also be put as revolutions per minute, etc. All points on a rotating disc have the same angular velocity about the centre, but their speed of motion increases with increasing distance from the centre.

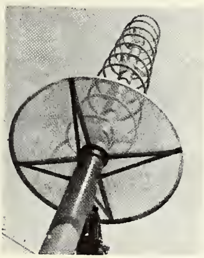
ANNULAR ECLIPSE. An eclipse of the Sun in which the Moon obscures the central part of the Sun's disc but leaves a thin ring of light showing. See **Eclipse**.

ANOMALISTIC YEAR. The time between two successive passages of the Earth through **perihelion.** See **Year.**

ANTARCTIC. The South Polar region within the **antarctic circle.** It contains the large land mass of the Antarctic continent. *Cf.* **Polar Regions.**

ANTARCTIC CIRCLE. The parallel of latitude 66° 33′ South. It is the limit of the area in the southern hemisphere within which the Sun does not set in mid-summer.

ANTENNA. A conductor linked to a radio transmitter for radiating, or to a receiver for intercepting radio waves. The size and shape of an antenna or *aerial* depend on the frequencies for which it is intended, on its directional properties, and on the reflectors and wave guides with which it may be linked.



A HELICAL ANTENNA, used to receive signals from test rockets in flight.

(*Lockheed Aircraft Co.*)

APHELION. The point furthest from the Sun of a planet's or comet's **orbit.** Contrary to what might at first be expected, the Earth passes through aphelion during mid-summer (of the northern hemisphere), the difference between the seasons being due much more to the inclination of the Earth's axis than to the changes in its distance from the Sun. *Cf.* **Perihelion.**

APOGEE. The position in the orbit of the Moon or artificial satellite which is farthest from the Earth. Opposite of **Perigee.**

APOLLO. A small asteroid which in 1932 came within 7 million miles of the Earth; track was lost of it as it receded again, and its present position is not accurately known.

δ–AQUARIDS. This **meteor** shower is best seen in the southern hemisphere, and is active for several days, during which the **radiant** is found to be in motion, with a maximum on May 5. The relation with **Halley's Comet** is doubtful, and radio-echo measurements give an orbit of period 11 years.

η–AQUARIDS. Best seen in the southern hemisphere, this **meteor** shower also occurs in historical records. The **radiant** is diffuse and has a daily motion of about 1°. The orbit is surprisingly small but very eccentric.

ARABIA. An ochre-coloured 'desert' region on **Mars.**

ARCTIC. The area within the **Arctic Circle.** See **Polar Regions.**

ARCTIC CIRCLE. The parallel of latitude 66° 33′ North. It is the limit of the area in the northern hemisphere within which the Sun does not set in mid-summer.

ARGON. A colourless, odourless gas of the **Helium** group which does not react chemically under ordinary conditions. It forms 0.94% of normal air.

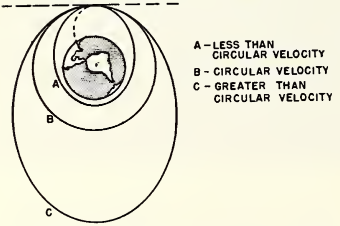
ARTIFICIAL SATELLITE. A man-made space vehicle placed into an orbit about one or more members of the solar system. An artificial *Earth satellite* revolves around the Earth as its primary, but it may also embrace the Moon in its orbit and gravitate—subject to many serious perturbations—about the common centre of gravity of the Earth and Moon; this centre lies within the Earth. A *Sun satellite* moves round the Sun and therefore constitutes an *artificial planet.* An artificial satellite may be simply the object of observations from the

Earth (*passive*) or it may record or transmit observations made by its instruments (*active*).

This article begins with a discussion of the general theory and uses of artificial satellites, and continues with a description of individual vehicles and a comparative table.

GENERAL THEORY: LAUNCHING PROBLEMS. Let us assume that it is intended to launch a satellite into its orbit round the Earth at 300 miles altitude. It is desired to have perigee, the closest approach to the Earth, not less than 200 miles above the ground. This could be done, for example, with an orbit having a semi-major axis of 4,500 miles. In such a case, if perigee were at 200 miles, then apogee, or the point of farthest recession from the Earth, would be at 800 miles.

ORBITS PRODUCED BY PROJECTING A SATELLITE PRECISELY HORIZONTALLY



The necessary speed for entry into this orbit is:

$$v_O = 25{,}500 \text{ ft/sec.}$$

The circular velocity corresponding to 300 miles altitude is:

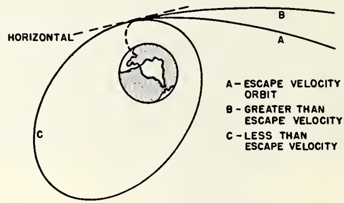
$$v_C = 25{,}000 \text{ ft/sec.}$$

Simply launching the satellite at the given speed will not ensure, however, that the perigee point will be at or above 200 miles. This must be achieved by careful guidance of the satellite so that the initial flight direction does not depart too greatly from the horizontal. If this angle with the horizontal is less than 2.9°, then perigee will be higher than 200 miles. If it is zero perigee would, of course, be the launching point itself, hence at a height of 300 miles.

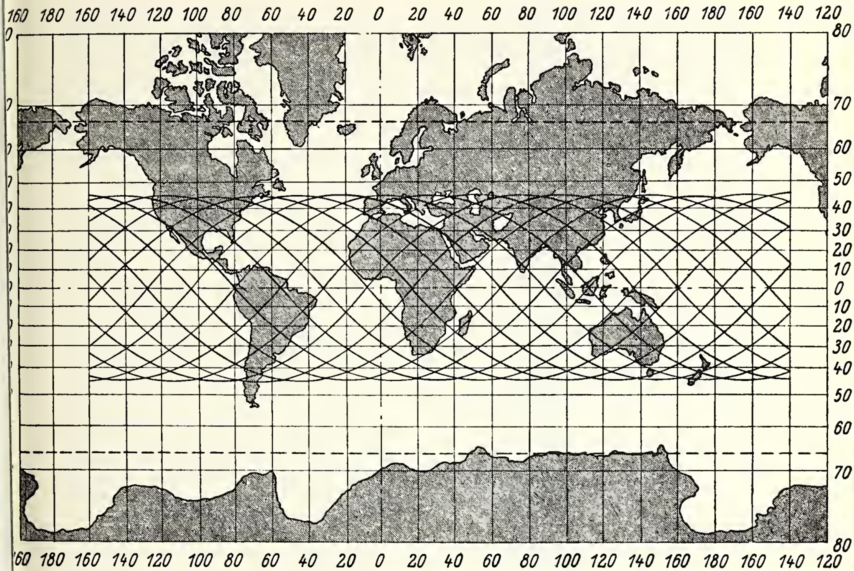
The guidance requirements would be even more stringent if the initial projection were made at a lower speed. For example, projecting at the circular speed of 25,000 feet per second, a perigee height of 200 miles or greater will be obtained only if the entry into the orbit is made at an angle within 1.3° of the horizontal. Similarly the guidance requirements would be eased if the initial projection were made at more than the 25,500 feet per second considered.

If we assume for the moment that the Earth is spherical, then the plane of the satellite's orbit is fixed in space and, once established, does not change. The same is true of the orbit itself. Both are unaffected by the rotation of the Earth. But the track of the satellite over the ground is not necessarily

DIFFERENT TYPES OF SATELLITE ORBITS



fixed, where by 'track' is meant the path followed by the point in which the line from the centre of the Earth to the satellite intersects the surface of the Earth. Since the orbital plane contains the centre, at any instant of time it intersects the Earth's surface in a great circle. But the eastward rotation of the Earth causes the points on this intersection to slide westward on the ground. Only in the case in which the track is the equator is there no change in the position of the track on the ground. In this equatorial case the principal effect of the Earth's rotation is to alter the apparent period of revolution of the satellite. In the very special case in which the satellite revolves eastward in the equatorial plane at 22,000 miles, it remains constantly above the same spot on the equator, since its period of revolution, being one day, coincides with that of the Earth's rotation.



THE PATH OF A SATELLITE in a circular orbit at a height of 346 miles, with the orbit inclined at 45° to the equator. While the Earth turns once round its axis, the satellite completes 15 circuits. At each return its path lies further to the West because the Earth has turned 24° to the East under it. The limits of visibility are shown by the broken lines in latitudes 67° North and South. At least twice each day the satellite is above the horizon of any point between these limits. The launching point may be anywhere between latitudes 45° South and 45° North.

When the satellite's orbital plane is inclined to the equator, the track on the ground weaves back and forth between a maximum northern latitude and an equal maximum southern latitude. In general the track in time pretty thoroughly criss-crosses the orbital belt between the northern and southern latitude extremes, although there are special effects when the period of the satellite bears some simple relation to one day. The reader may be interested, for example, to consider what the track would be if the satellite's period were exactly one day, corresponding to a circular orbit at 22,000 miles altitude; or 1/12 day, corresponding to a circular orbit at about 1,000 miles altitude.

For a polar orbit the satellite will pass over each pole once each revolution. In general its track will criss-cross the entire Earth, although again there are special cases which the reader may wish to consider.

If the satellite were launched at a point of latitude L, then its orbit would have an inclination to the equator of at least L degrees. The inclination would be exactly L degrees if the vehicle were launched either due east or due west. When fired either north or south of east or west, the satellite would follow an orbit inclined at more than L degrees to the equator. Thus an equatorial orbit could be obtained only if the launching were made directly above the equator, and then only by launching due east or due west.

EARTH SATELLITES - THE ACTUAL EARTH. The discussion of the preceding section was based upon the assumption that the Earth is a perfect sphere. Many of the results so obtained are adequate both qualitatively and quantitatively to define the problems involved in launching an artificial satellite and in placing ground stations for observing it. But there are some important effects which are missed in the approximate treatment.

The Earth is *not* a perfect sphere (see **Hayford Spheroid**). The polar radius is some 13 miles shorter than the radius at the equator. This equatorial bulge shows up in a modification of the gravitational field of the Earth.

Qualitatively the effect of the bulge can be thought of as follows. As the satellite approaches the equator in its motion around the orbit, the excess mass in the bulge pulls the satellite out of its orbital plane. If the satellite revolves with an eastward component, the effect is to cause it to cross the equator to the west of where it would otherwise have crossed. The overall result is that the orbital plane revolves slowly in space, and the equatorial crossings, or nodal points, slide westward around the equator.

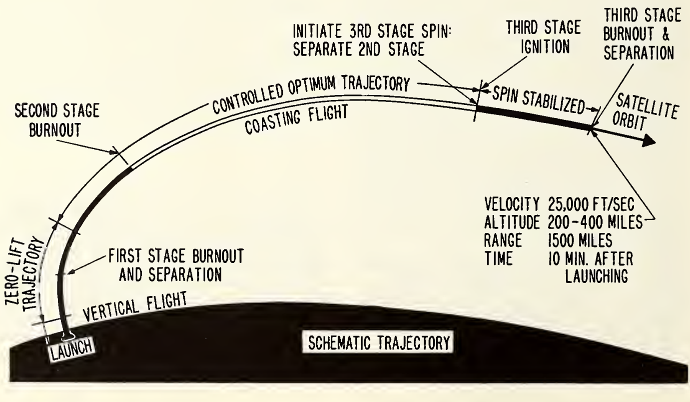
For a satellite near the Earth revolving in an orbit with a very small inclination to the equator, the period of this regression of the **nodes**, as it is called, is about 44 days. This motion also causes the track of the satellite to slide westward over the ground, and adds to the much greater westward movement caused by the Earth's rotation. The period of the nodal regression increases with the secant of the orbital inclination to the equator, becoming infinite for a polar orbit.

Period of Revolution of a Satellite in a Circular Orbit about the Earth

Height above the Earth (Miles)	*Approximate Period*
200	90 minutes
1,000	2 hours
22,000	1 day
235,000	1 lunar month

In the case of a satellite revolving in a westerly direction, the nodal regression carries the equatorial crossing points eastward around the equator. The resulting motion of the satellite's track then subtracts from the westward motion due to the Earth's rotation. Except for this the westward case is equivalent to the eastward one.

A second effect of the equatorial bulge is to cause the positions of perigee and apogee



to advance around the orbit. As the satellite approaches the equator, nearing perigee, the excess mass speeds up the satellite temporarily in its orbit, causing it to overshoot the original perigee point and to arrive at perigee a short while later. This motion of perigee and apogee will cause the height at which the satellite passes over a given region of the Earth to vary with time.

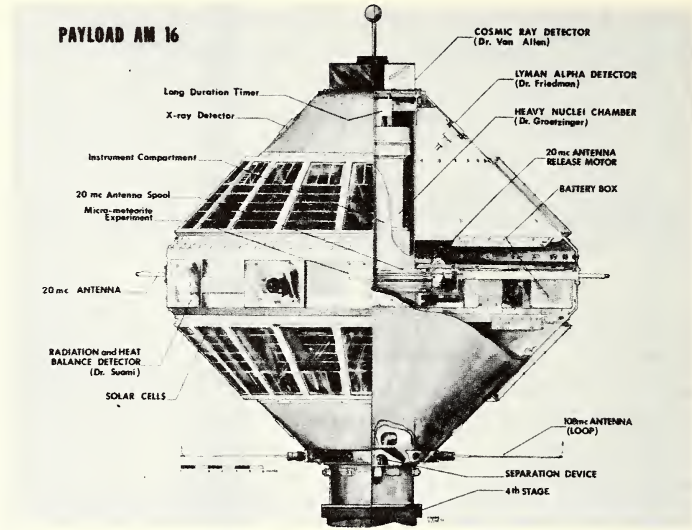
A third, but very much smaller, perturbation affects the motion of small satellites close to the Earth's surface. It arises from irregularities in the distribution of mass in the Earth's crust.

To ignore the atmosphere, as was done in the preceding section, is completely unrealistic. Although the air is exceedingly rarified at the altitudes under discussion, the speed at which satellites move is so great that there is a noticeable drag effect for orbits with a low or moderate perigee. This causes a steady degeneration of the orbit, the satellite tending to move closer to the lower atmosphere. The drop in mean height represents a loss of potential energy which shows up as increased kinetic energy, *i.e.* during this regime the satellite actually speeds up. It is therefore not proper to say that the drag 'slows down' the satellite at this stage.

Eventually the orbit degenerates to the point where enough of the satellite's motion is through denser air to cause drag to have a dominating influence, and the vehicle begins to slow down. Energy is now taken up by tremendous aerodynamic heating which, in the absence of special re-entry techniques, burns and vaporises the whole or part of the vehicle. The satellite disintegrates like an exploding meteor, lighting up the whole sky for a few moments from a height of some 65 miles.

TRACKING A SATELLITE. It is obviously necessary to know the position of a satellite at a given time with the greatest possible accuracy. For this purpose it may be tracked optically or by radio.

As soon as the rockets are burnt out, optical tracking must depend on the illumination provided by the Sun. The requirements are that the observer be in the dark, the satellite be in the sunlight, and that the sky background be not too bright; that is to say, the satellite can be visible to the observer only shortly after sunset or just before sunrise. If it is at a moderate height of a few hundred miles, it



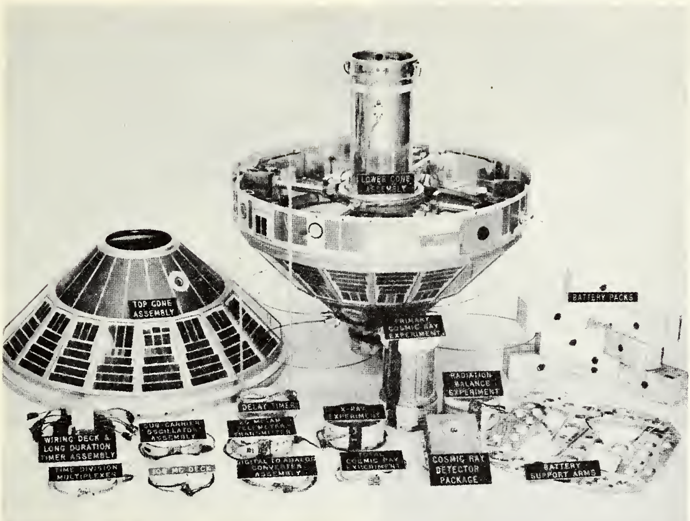
EXPLORER VII. *Above:* the entire satellite with part of the hull on the right cut away. Depth 33″ width 30″. *Opposite:* the same satellite dismantled. The solar cells contain a variety of experimental panels. The cylindrical packages fit on the rods above the delay timer and are then inserted into the central tube. (*U.S. Army Missile Command.*)

passes through the region of visibility in a matter of minutes, and during that time its orientation may be such that it reflects the minimum of light towards the observer. At greater distances the satellite spends a shorter proportion of time in the Earth's shadow and might be observable all night, but the intensity of light received from it falls off rapidly with increasing distance. Optical and photographic tracking is therefore severely limited but gives the most accurate results.

Radio tracking may be passive (without depending on signals emitted by the satellite) or active. It is virtually independent of weather and the time of day, and has in practice greater range but less precision than optical methods. (See also **Minitrack** and **Radio Astronomy**.)

USES OF SATELLITES. Many scientific enquiries concerning the upper atmosphere and interplanetary space could until recently be pursued only by indirect methods and inference; others could not be carried on from the Earth at all because of the blanketing effect of the atmosphere or, occasionally, because they required the conditions of **free fall** which even in rockets are attained only for a few minutes. Vertical sounding rockets afford no more than a brief glimpse of conditions at any level, while artificial satellites provide a relatively permanent platform for continuous observations over long periods. This opportunity has now been applied to research on the following topics:

(1) The intensity of electromagnetic and corpuscular radiation from the Sun at different levels. Nearly all the probes launched so far have carried instruments (spectrographs, photomultipliers, electrostatic fluxmeters or



ionisation gauges and counters with varying shielding and filters) to measure these quantities. It has been established that the **ionosphere** is lower than was previously believed, and that its strata are not sharply defined and are subject to local, transient anomalies.

(2) **Cosmic rays.** Particles have been recorded with energies up to a billion billion electron volts, and the flux of heavy nuclei is found to be very low.

(3) Meteoric and interplanetary dust. Explorer I, Lunik I and later probes have carried **micrometeorite** gauges which measure the erosion of the surfaces of thin plates exposed to the impact of the dust by detecting changes in the conductivity of the plates. Piezo-electric pickups and microphones have been used to record the kinetic energies of micrometeorites striking their surfaces. It is assumed that Lunik III ceased to transmit upon being punctured by a **meteor.**

(4) The shape and extent of the Earth's magnetic field, and the **van Allen** radiation belts. The existence of these belts was first demonstrated by Pioneer I and Pioneer III; magnetometers flown in the lunar probes have helped to map them to a distance of over 90,000 miles from the Earth.

(5) Distribution of mass in the **Earth** and its equatorial bulge; checks on longitude determinations and the **Astronomical Unit**. Irregularities in the conformation of the Earth cause **perturbations** of satellite orbits.

(6) Conditions in space near the **Moon**; its magnetic field and the appearance of the 'far' side. Lunik II confirmed the belief that the Moon's magnetic field is extremely weak; Lunik III photographed the hidden side and relayed the pictures to Earth.

(7) Effects of radiation and prolonged free fall in animals, particularly mammals.

(8) **Airglow, radiation pressure,** and thermal equilibrium of a vehicle in space.

(9) Relay and reflection of radio, radar and television signals by satellites. *Project Score* was successfully used to relay messages. Difficulties have been encountered in transmitting through the ionosphere, and through the formation of an ionised 'sheath' round bodies moving in the atmosphere.

(10) Time measurements comparing a clock in a satellite with one on the ground to test relativity predictions on **time dilatation.**

(11) Photography of other members of the solar system from space, where there is no atmospheric absorption and perfect seeing. The Earth's cloud cover.

(12) Orbital decay, **air drag.**

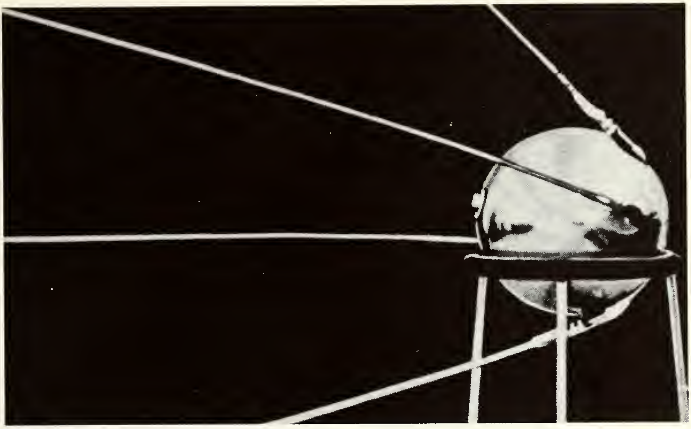
(13) The use of solar batteries in providing power for instruments and transmitters.

THE FIRST SATELLITES.

SPUTNIK I. On October 4, 1957, the first of a series of artificial satellites was placed into orbit by scientists of the Soviet Union. The most outstanding features of this achievement were the unexpectedly great weight of the satellite, and the high inclination of its orbit.

This satellite carried little instrumentation other than two transmitters, and most of its weight was taken up by the batteries which supplied the necessary power for three weeks. This weight was about nine times that of the original design for the *Vanguard* sphere. It is much easier to double the height attained by a rocket than to double its payload, and the Russian success on this point was most significant, especially when one remembers that for military applications it is the payload, *i.e.* the warhead, that matters.

The easiest direction in which to launch a satellite is more or less due East, when it receives the full benefit of the eastward rotation of the Earth. Considerably more power is needed to place it into an orbit which makes a steep angle with the equatorial plane, but such an orbit covers a greater part of the Earth's surface. In other words, by choosing an orbit inclined at almost 65°, the Russians demonstrated that their first launching vehicle had power to spare. The fact that some of their



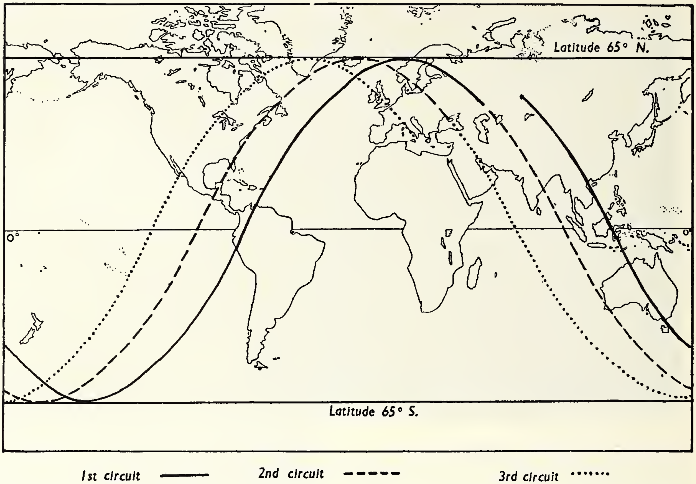
THE FIRST RUSSIAN SATELLITE on a tripod stand prior to loading into the final section of its launching vehicle. Its four aerials are shown partly unfolded. The surface of the thin spherical shell is highly polished so as to reflect heat and offer the minimum resistance to the outer atmosphere.

later satellites had almost exactly the same inclination testified to great accuracy in introducing the satellites into their orbits.

When the last stage of the launching vehicle sent the satellite into its orbit at a speed of about 18,500 m.p.h., it was of course at the same height, but the recoil from pushing the sphere forward to detach it slowed the rocket down slightly so that it dropped a little lower and a little sooner to its perigee (nearest approach to Earth) than the satellite itself. By losing more height, *i.e.* falling further, the rocket actually *gained* in speed and presently overtook the satellite, travelling about 15 miles below the latter and increasing its lead at every circuit. However, the large surface of the rocket caused it to experience more air resistance than the satellite. At first, this drag was almost negligible for both, and indeed much less than had been expected; but presently the rocket touched lower and therefore denser levels of the outer atmosphere, and air drag became more than enough to offset the speed gained through the rocket's gradual fall, so that in fact it slowed down and was in its turn overtaken by the satellite.

Magnified portion of satellite track. The changing aspect of the tumbling, elongated body of SPUTNIK III causes varying amounts of sunlight to be reflected towards the observer. From the fluctuating brightness of the trail, the spin and orientation can be calculated.

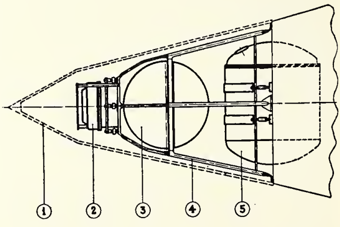
The bright object which was visually observed moving in a few seconds from horizon to horizon was the last stage of the rocket and not the satellite itself. Spinning slowly as it travelled, it presented varying areas of its surface to observers, and this led to the regular fluctuations in brightness which showed up in photographs of its trail. It could,



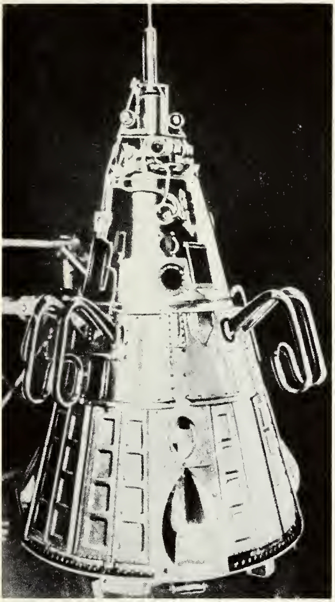
THE ORBIT OF THE FIRST SATELLITE. The above map shows the points over which the satellite passed in the course of three revolutions round the Earth, which it completed in under five hours. Starting in Russia, it first crosses the equator at an angle of 65° to the latter East of Borneo. By the time of its next return the Earth has rotated eastward under it, and the satellite now passes over the Indian Ocean. After 10 hours it will have been within sight of every point between latitudes 65 N. and 65 S. at least once.

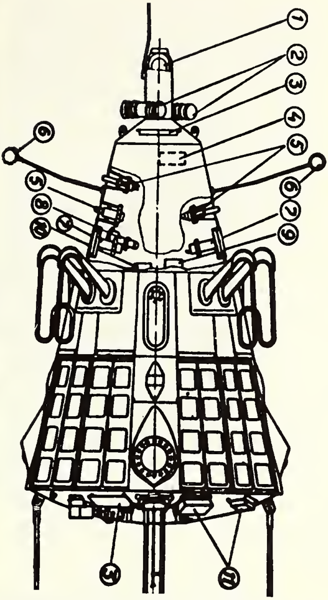
of course, only be seen near dusk or dawn, when the sky as a whole still appeared fairly dark but the rocket had not yet entered the Earth's shadow on the night side or was just emerging from it. Occasionally the rocket had an apparent magnitude of -4, *i.e.* some ten times as bright as Sirius.

Had the satellite been placed into a much higher orbit it would have been of less use. The point of greatest interest at that time was the manner in which its movement was affected by drag; by dipping from what is for all practical purposes interplanetary space to the outermost fringes of the Earth's atmosphere and very gradually penetrating deeper at succeeding circuits, the satellite provided exactly the kind of information that was required—not only for furthering the conquest of space, but more immediately for the development of intercontinental missiles.

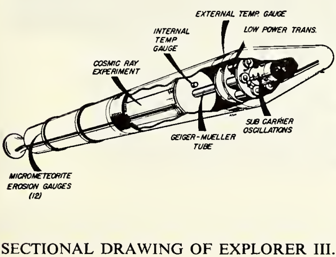


DIAGRAMMATIC CROSS SECTION OF SPUTNIK II. (1) Protective cone which drops off as satellite enters orbit. (2) Instruments for measuring solar, cosmic and X-ray radiation. (3) Transmitter housing. (4) Framework. (5) Sealed cabin for dog.

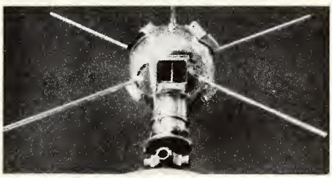




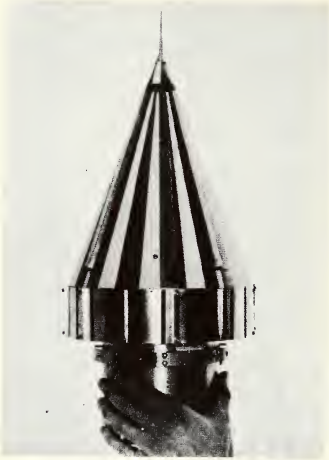
THE THIRD RUSSIAN SATELLITE. The drawing and the photograph show it from slightly different angles: (1) magnetometer to measure gravity; (2) photo-multipliers to measure corpuscular irradiation from the sun; (3) solar batteries; (4) and (5) counters; (6) ionic traps; (7) electrostatic fluxmeter; (8) mass spectrograph; (9) counter for heavy nuclear particles in cosmic rays; (10) apparatus to measure intensity of primary cosmic rays; (11) micro-meteor impact counter. The long curved tubes are part of the equipment for heat exchange and measurement.



SECTIONAL DRAWING OF EXPLORER III.



VANGUARD I. $6\frac{1}{2}$ ins. in diameter and weighing $3\frac{1}{4}$ lbs., this satellite is considerably smaller than the original design. The rectangular objects are solar batteries which power the transmitter for an indefinite time.



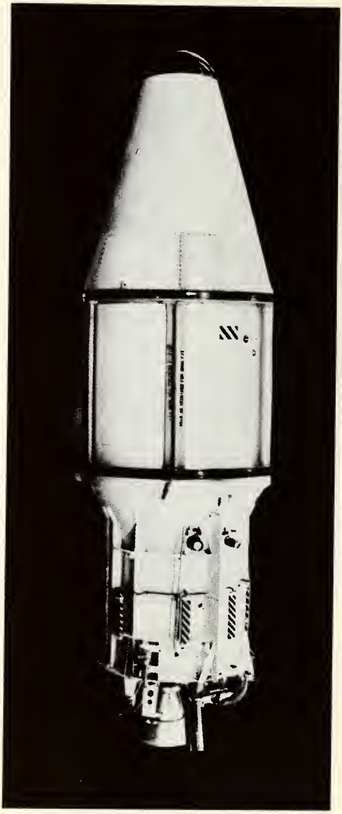
PIONEER IV. This satellite, intended as a moon probe, is now an artificial planet in orbit round the Sun. The fibreglass outer cone is gold-washed to provide conductivity. The striped pattern is painted on to regulate temperature by controlling reflection and absorption of solar heat.

SPUTNIK II. The second Russian satellite was a much larger structure weighing half a ton, and carried instrumentation for measuring the respiration, heart-rate and blood pressure of a dog carried in its after-compartment. The dog was exposed to all forms of radiation and lived for about a fortnight. During this time it appeared to be in relatively good health, but the full effects of radiation sickness could not be observed.

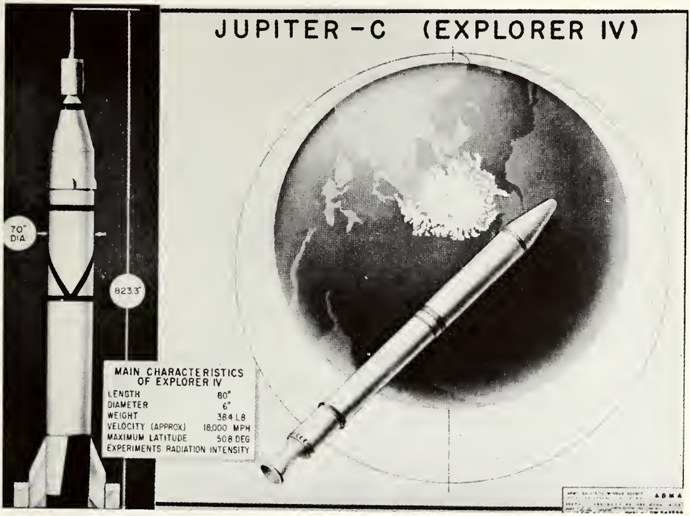
EXPLORER I. After a number of the more sophisticated Vanguard rockets had failed, the first American satellite was carried into orbit by an adaptation of the U.S. Army's Jupiter-C. It provided the first direct data on the density of matter in interplanetary space well outside the exosphere.

The launching vehicle consisted of four stages: the propellents of the first were Hydyne and liquid oxygen; the second, third and fourth stages had 11, 3 and 1 solid-propellent rockets respectively.

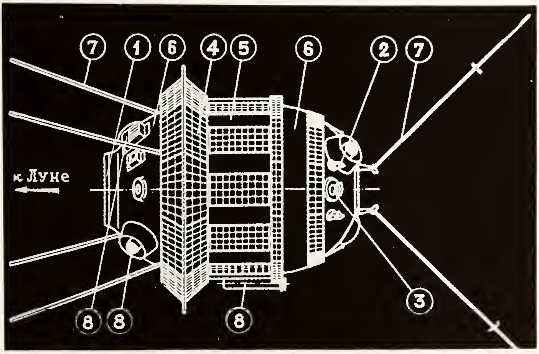
Details of these and subsequent satellites will be found in the accompanying table.



DISCOVERER. Final stage containing satellite assembly. Length 19 ft.



EXPLORER IV, its launching vehicle, and a scale drawing of the orbit relative to the Earth.



LUNIK III, also called *Cosmos III*. This is the vehicle which carried out a photo-reconnaissance of the Moon. (1) Camera lenses. (2) Motor of orientation system. (3) Solar monitor (sun-seeker). (4) Solar battery panels. (5) Shutters of temperature regulating system. (6) Part of heat screen. (7) Aerials. (*Tass*)

LUNIK I and shortly afterwards PIONEER IV were the first man-made vehicles to escape from the Earth altogether. Both were intended as lunar probes; having departed very slightly from their planned trajectories they passed the Moon and entered into an orbit around the Sun, thereby becoming artificial planets or Sun satellites.

LUNIK II was the first man-made object to strike the Moon. It fell at a speed of 2 miles per second in a position about 500 miles north of the centre of the visible disc. It transmitted information on the Moon's very weak magnetic field up to the moment of impact.

LUNIK III circumnavigated the Moon and photographed 70% of the averted side (see picture under Moon). All equipment in this satellite was duplicated. If any part broke down, it could be replaced from the reserve equipment by a radio signal from the Russian ground stations.

On reaching a position 40,000 miles from the Moon on a line between the Moon and the Sun, gyroscopic apparatus stopped the satellite's spin. Then one end was directed towards the Sun by a **sunseeker**. This roughly aligned the other end, containing the cameras, with the Moon. Another optical unit trained the cameras more precisely until a 'Moon in' signal triggered off the automatic photographic process.

The satellite then set itself spinning again to equalise temperature conditions. Shielded from cosmic rays as far as possible and under conditions of weightlessness, the films were developed, fixed and dried. When the vehicle had circumnavigated the Moon and was again fairly close to the Earth it began to transmit the pictures to the ground stations.

Work is progressing on placing manned satellites with recovery capsules into orbit (see Mercury Project); on 'soft' landings on the Moon of robot observing stations, which require reserves of fuel for retardation of the vehicle immediately before landing; on planetary probes, and on a variety of military projects.

ORBITS OF LUNAR PROBES.

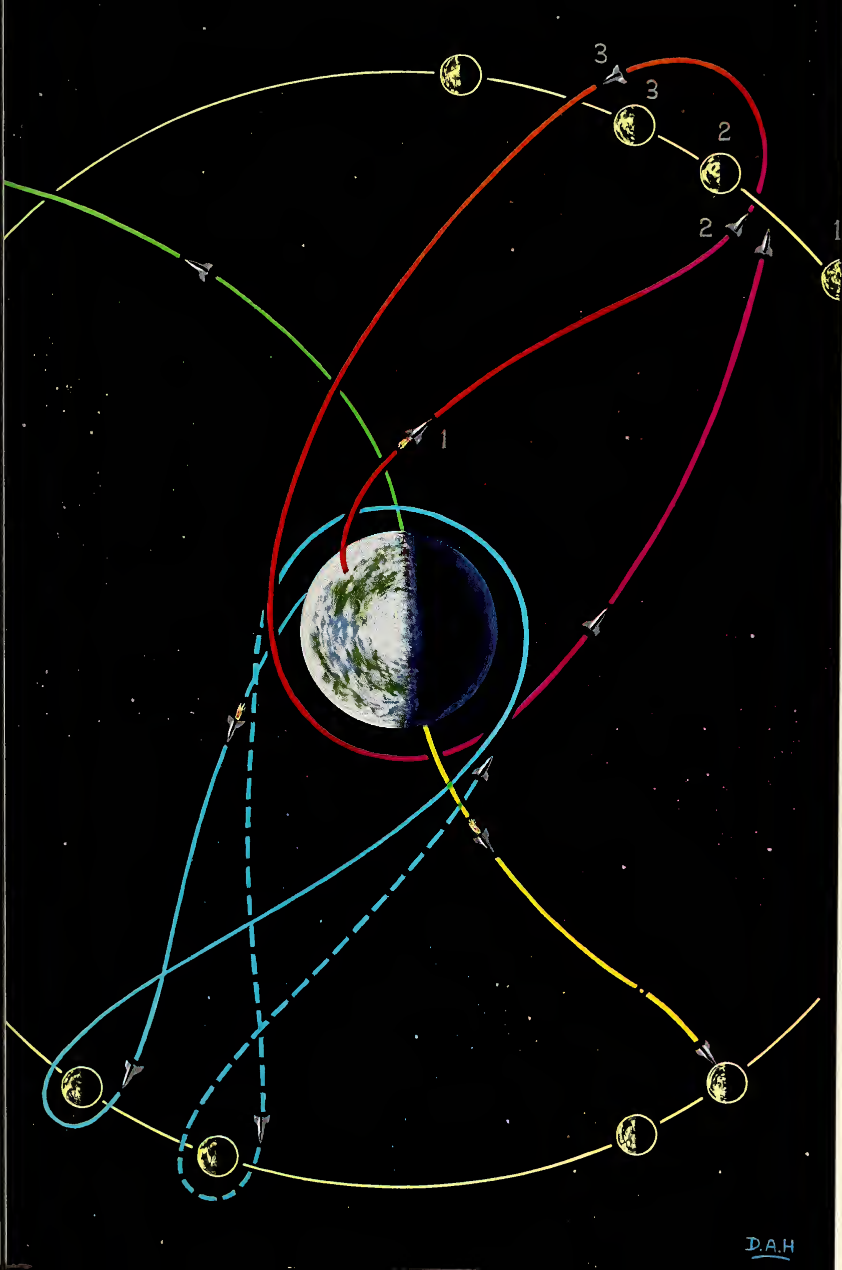
Yellow Orbit: this is the path of a probe which falls on the Moon, such as *Lunik II.* The dot break in the yellow line indicates the Neutral Point, where the Earth's gravitational pull is exactly counterbalanced by that of the Moon. From the time of all-burnt up to reaching the neutral point, the rocket loses speed and its orbit curves towards the Earth; beyond the neutral point, it gathers speed and turns towards the Moon. It strikes the surface with a speed not less than the Moon's escape velocity, unless retro-rockets are fired to give a soft landing. Each of the other orbits passes through a neutral point of its own.

Red Orbit: circumnavigation of the Moon by *Lunik III.* Each rocket symbol along the path corresponds to the Moon position marked with the same number. This applies also to the other orbits, but the numbers have not been inserted on them. The Moon's orbit round the Earth lies in the plane of the paper; the orange part of Lunik III's track lies above this plane, and the cherry-coloured part below it. Closest approach to the Moon was made shortly after position 2. The rocket was then 'dragged' along by the Moon's motion towards position 3. On its next return the rocket misses the Moon altogether and gradually relapses into an elliptical Earth satellite orbit.

Green Orbit: the first artificial planets were intended to be lunar probes. This orbit shows the path of a vehicle intended to go straightaway into a circumsolar orbit. It is shown as the path of a dawn rocket, leaving the Earth from a point in the morning twilight. In this diagram, we look down upon the Arctic, and the Earth rotates counterclockwise. The neutral point of the green orbit does not lie within the picture.

Blue Orbit: this is a possible orbit, but it could be maintained only with short ground-controlled bursts from the rocket motors each time the probe recedes from the Earth. In all the other cases, the rockets cease firing once and for all within a few minutes after launching. The blue orbit shifts counter-clockwise in step with the Moon's monthly revolution round the Earth. Since the rocket can carry only a limited supply of propellents, it cannot remain in this orbit indefinitely except by the use of solar energy on a scale which has not so far been attempted.

None of this diagram is drawn to scale, nor can a time scale be applied to it as we have not specified the velocities of the rockets. The Moon is shown throughout in the phase corresponding to that of the Earth, but to an observer on the Earth it would appear gibbous and waning at the top of the picture, and waxing from crescent to gibbous in the lower half. (*Diagram by David Hardy, F.R.A.S.*)


3
3
2
2
1
1
D.A.H

A TITAN MISSILE during preparation for firing. The gantry is being lowered into a horizontal position. Propellents are pumped through the pipes leading from the tower on the right into the tanks of each stage. The pipes feeding the first stage will disconnect themselves from their rip sockets during ascent of the rocket. Clouds of vapour condense and drift past the refrigerated hull.

EARTH AND MOON viewed at 480,000 miles from the Earth. Details of the Moon are based on *Lunik III* photographs (see p. 183); the Sovietsky Mountains are clearly visible. Near the Earth's poles aurorae can be seen faintly. The clouds at the edge of the sunlit area are tinged with red and yellow—the atmospheric ' sunset ' effect.

DATA	Sputnik I 1957 α U.S.S.R.	Sputnik II 1957 β U.S.S.R.	Explorer I 1958 α U.S.A.	Vanguard I 1958 β U.S.A.	Explorer III 1958 γ U.S.A.
LAUNCHING	1957, October 4	1957, November 3	1958, February 1	1958, March 17	1958, March 26
TYPE	Earth satellite	Earth satellite	Earth satellite	Earth satellite	Earth satellite
ORBIT					
initial period (min.)	96.2	103.7	114.9	134.2	115.7
inclination	64.9°	65.3°	33.5°	34.25°	33.37°
eccentricity ..	0.06	0.105	0.14	0.20	
max. height (miles)	592	1,045	1,587	2,466	1,735
min. height (miles)	142.5	140.6	217	409	125
LIFETIME	92 days	$5\frac{1}{2}$ months	3–5 years	Indefinitely long	Three months
WEIGHT (LB.)					
total	184.3	1,118.3	30.8	53	30
instruments ..		554	10.6	3.25	10.8
SHAPE	Sphere	Cone and cylinder	Long cylinder	Sphere	Cylinder
INSTRUMENTATION ..	Two transmitters, temperature and pressure meters, magnetometer, radiation counter, batteries	Transmitters, three photomultipliers for spectroscopic studies, cosmic ray counters, biological equipment	Two transmitters, cosmic ray counters, temperature and micrometeorite gauges	Solar- and battery-powered transmitters, temperature meter	Tape recorder and as Explorer I
PRIMARY AIMS ..	Preliminary investigations. (Believed to be tenth launching attempt)	Study of effect of environment on dog passenger	See instruments. Discovered van Allen belts. (Believed second launching attempt)	Radio-tracking and air-density measurements	Similar to Explorer I
LAUNCHING VEHICLE	Three-stage (T-4?)	Three-stage	Jupiter-C	Vanguard	Jupiter-C

The aims of recent and current development of artificial satellites may be broadly grouped under four headings, although many projects serve some or all of these purposes at once: (1) Astronomical research and pure science; (2) Missile technology; (3) Communications; (4) Meteorology.

Although the first of these is in some senses the most important aspect of space research, the progress that has been made is largely a by-product of missile development. AEROBEE rockets continue to probe the upper atmosphere. The series of EXPLORER geophysical satellites have provided a vast mass of data on conditions in space relatively close to the Earth, and have carried a number of optical and electronic astronomical instruments well beyond the turbulence of the Earth's atmosphere and its opacity to most forms of radiation. The PIONEER deep-space probes and Russian vehicles of the type of 1961 γ 1 have extended the survey into a considerable belt of interplanetary space, and have sampled the neighbourhood of Venus and Mars. Such planetary probes, as well as most lunar probes, ultimately become satellites of the Sun and move in truly planetary orbits. The PIONEER V **Venus Probe** was particularly successful in communicating over a vast range, and in the sensitivity of the measurements it made. These probes have also yielded confirmation of relativistic effects and a correction of the fundamental **Astronomical Unit.**

Biological and medical research have benefited most from the manned vehicles of the MERCURY and VOSTOK series. It has been established that man and woman alike can endure weightlessness for limited – and probably for prolonged – periods, that they can take an active part in the control of the vehicle and its instrumentation, and that they can be protected against the stresses of launching and re-entry. Many other forms of life, including algae and plants, have been carried in rockets to establish mechanical and radiation tolerances, and to observe changes in their physiology during free-fall.

It is impossible to mention individually all the satellites that have contributed to missile technology. The basic problems of landing, calculating and controlling the trajectory, communication with a control centre and **re-entry** have been solved, but need constant refinement to meet the threat of the anti-missile missile. Early detection and monitoring of foreign launchings have stimulated the development of satellites with a large 'field of view', which can transmit at any time of day to any point on the surface of the Earth. This can be achieved by placing three or more satellites in a more or less fixed position above the Earth, in the manner of SYNCOM II. The NEEDLES are related to this problem. By dispersing a vast number of very fine metallic dipoles in a band stretching around the entire orbit, a global reflecting layer for radio transmissions of certain frequencies has been provided, to the great detriment of radio astronomy.

Communications satellites are either passive like ECHO, which is a balloon inflated in orbit with a reflecting surface, or active like TELSTAR, which receives, amplifies, re-shapes and re-transmits radio signals including television.

TIROS and NIMBUS are weather-observation satellites which transmit from their own television cameras together with their scanning of infra-red heat in the troposphere.

Current American projects include the following:—

GEMINI, for placing two men in space and practising rendezvous techniques;

APOLLO, a three-man space craft for flight to the vicinity of the Moon and manned landings;

OAO, for astronomical observations from space with a 36-inch optical telescope;

RANGER, a rough-landing lunar probe for exploring the surface by seismographic studies after impact;

SURVEYOR and PROSPECTOR, soft-landing lunar probes which will have controlled mobility on the surface;

RIFT, a test-bed for a nuclear rocket engine, and ROVER, to follow on from it for long-range missions;

SERT, or Space Electronic Rocket Test, for developing **ion rockets**;

TRAILBLAZER, a solid-propellent, seven-stage rocket for high-velocity re-entry studies;

VOIS, or Visual Observation Instrumentation Sub-system, for photographic mapping of lunar and perhaps planetary surface features.

DATA	Lunik II	Lunik III	Pioneer V	Tiros I
		1959 θ	1960 α	1960 β
	U.S.S.R.	U.S.S.R.	U.S.A.	U.S.A.
LAUNCHING	1959, September 12	1959, October 4	1960, March 11	1960, April 1
TYPE	Moon probe	Moon probe	Venus probe	Earth satellite
ORBIT				
initial period (min.)		15 days 5 min.	312 days	99.15
inclination	65°	75°	3.35° to ecliptic	48.3°
eccentricity		0.82	0.104	0.0045
max. height (miles)	Landed on Moon	292,000	92.3 m. (aphelion)	407
min. height (miles) ..		25,000	74.9 m. (perihelion)	372
LIFETIME	34 hours	6 months	Indefinitely long	?
WEIGHT (LB.)				
total	3,332	3,300	90	270
instruments	860	959		
SHAPE		Barrel	Sphere with solar paddles	
INSTRUMENTATION ..	Radiation counters, magnetometers, telemetry	Telemetry, cameras, orientation motors, solar monitor, thermo-regulator, solar battery	Two transmitters, two counters, micro-meteorite gauge, magnetometer, aspect indicator	Two transmitters, two T.V. cameras, one with two lenses. 9,000 solar cells
PRIMARY AIMS ..	Landing on Moon	Photo reconnaissance of Moon		Weather research
LAUNCHING VEHICLE ..			Thor-Able III	Thor-Able III

DATA	Venus Probe 1961 γ 1 U.S.S.R.	Explorer XI (S-15) 1961 ν U.S.A.	Luna IV 1963–08A U.S.S.R.	Telstar II 1963–13A U.S.A.	Needles 1963–14F U.S.A.
LAUNCHING	1961, February 12	1961, April 27	1963, April 2	1963, May 7	1963, May 9
TYPE	Venus probe	Earth satellite	Moon probe	Earth satellite	Earth satellite
ORBIT					
initial period (min.)	10 months	107.8	42,000?	225.05	166.5
inclination	0.5° to ecliptic	28.80°	—	42.73°	87.4°
eccentricity ..	0.17	0.086	0.8?	0.401	0.004
max. height (miles)	closest approach	1,105	450,000?	6,713	2,287
min. height (miles)	to Venus < 65,000	303	55,000?	605	2,239
LIFETIME	Many years	150 years	Indefinite	600,000 years	5 years?
PAYLOAD (LB.)	1,419	95	3,135	175	51
SHAPE	Cylinder	Cylinder	—	Spheroid	Annulus
MAIN FUNCTIONS ..	Accepts radio commands from earth; transmits data on cosmic rays, magnetic field, interplanetary gas, corpuscular streams from sun, micro-meteors; has equipment for turning and stabilizing in orbit.	Survey of sky by gamma ray telescope for cosmic gamma radiation from all directions in space.	Measurements of corpuscular streams from sun, effects of radiation on organisms carried in probe, and observations relating to the nature of the moon's surface and possible atmosphere. Precise observation of trajectory, including optical tracking for 87,000 miles.	Receives, amplifies and re-transmits radio transmissions including television. Measures incidence of electrons in the 1 m.e.v. range. Powered by 3,600 solar cells.	A vast number of very fine metallic needles was released in orbit at slightly varying velocities, dispersing them ultimately in a ring-shaped band extending over their entire orbit. This band can reflect radio waves round the earth at any time of day. Possible applications for missile guidance and detection.

DATA	Mercury IX (Faith VII) 1963–15A U.S.A.	Vostok VI 1963–23A U.S.S.R.	Syncom II 1963–31A U.S.A.	General
LAUNCHING	1963, May 9	1963, June 16	1963, July 26	By the end of 1962, a total of 140 successful launchings had placed in orbit –
TYPE	Earth satellite	Earth satellite	Earth satellite	
ORBIT *initial period (min.)* *inclination* .. .. *eccentricity* .. *max. height (miles)* *min. height (miles)*	 88.74 32.54° 0.008 166 100	 88.2 65.09° 0.004 135 102	 1,454.0 33.05° 0.013 22,800 22,111	instrumented satellites 151 separated rockets 61 other fragments 264 TOTAL 476
LIFETIME	1.44 days	2.95 days	Indefinite	
PAYLOAD (LB.) ..	3,020	11,023	86	At that time there remained in orbit –
SHAPE	Cone frustum	Cone cylinder?	Cylinder	instrumented satellites 55 separated rockets 27
MAIN FUNCTIONS ..	Further development of Mercury Project (*q.v.*). First manned satellite in which the astronaut exercised partial control over orbital corrections, stabilization and re-entry. Experiments on medical effects of prolonged weightlessness and other tolerances in astronaut. A stepping stone towards Project Gemini.	First space-flight by woman. Communication with other manned satellite (Vostok V). Approach of the two vessels to within a few miles. Wide range of space medical experiments; partial systems control by astronaut.	A communications satellite with an orbital period close to 24 hrs., which tends to maintain it in a constant longitude. This would be a fixed-point satellite if the inclination of its orbit to the equator were 0°.	other fragments 193 TOTAL 275 The remainder had decayed, burning up in the atmosphere on re-entry, or had been decelerated for re-entry and recovery on the ground (about 28). During 1963 these numbers were almost doubled.

ASTEROID or *Minor Planet.* The many thousands of small worlds, revolving round the Sun mainly between the orbits of Mars and Jupiter, are known collectively as asteroids; alternative names are minor planets and planetoids. All are insignificant, the largest (**Ceres**) being less than 500 miles in diameter.

DISCOVERY. In 1772 Johann Bode drew attention to a curious numerical relationship between the distances of the planets, discovered some years earlier by Titius of Wittenberg (see **Bode's Law**), and concluded that there should be an extra planet revolving between Mars and Jupiter. In 1800 six German astronomers, headed by the famous lunar observer Schröter, determined to make a serious effort to track down the missing body; but before their scheme could be brought into working order, Piazzi, at Palermo, discovered a starlike object which proved to revolve at the correct distance from the Sun. It was named *Ceres*.

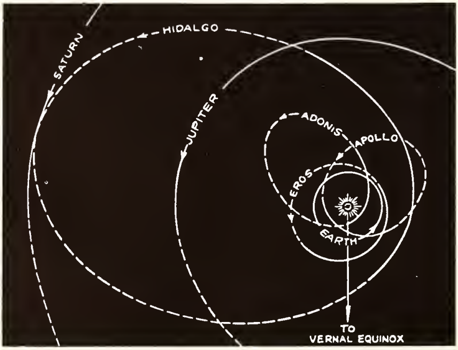
Olbers, a member of Schröter's 'celestial police', discovered a second small planet (*Pallas*) in 1802; *Juno* followed in 1804, and *Vesta* in 1807. The fifth member of the group, *Astraea*, was not discovered until 1845, but since then minor planets have been found in great numbers. Over 1,500 have now had their orbits computed, and the total number has been estimated as 44,000, though many of these must be too small and faint to be detected.

ORBITS. Most of the minor planets revolve at distances from the Sun intermediate between those of Mars and Jupiter. The average orbital eccentricity is 0.15, but some particular members exceed this greatly; examples are **Albert** (0.54) and **Hidalgo** (0.65). The inclinations also show a wide range, from 43° (Hidalgo) down to almost nil. No minor planet with **retrograde motion** has been discovered.

In 1886, D. Kirkwood showed that minor planets are scarce in regions which would involve a period which is a simple fraction of Jupiter's. Jupiter causes, in fact, definite gaps in the main asteroid zone, known generally as the **Kirkwood Gaps**. A similar effect is seen with regard to Saturn's rings, due to the influence of the satellites of that planet (see **Saturn**).

Some exceptional asteroids have orbits which carry them well away from the main swarm. Some, the **Trojans**, revolve in the orbit of Jupiter; others have orbits which carry them even beyond – Hidalgo moves from the orbit of Mars out almost to that of Saturn! – and yet others invade the inner regions of the Solar System, one asteroid (**Icarus**) having a perihelion distance less than that of Mercury.

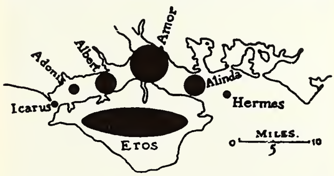
NAMES. The first asteroids to be discovered were dignified by mythological names (*Ceres*, *Hygeia*, *Metis*, *Psyche*, *Thalia* and others). Unfortunately the supply of goddesses



SOME UNUSUAL ASTEROID ORBITS. Most asteroids have nearly circular orbits and move in a belt between Mars and Jupiter, but a number of exceptions are known, and there may be many more. Although the planetary and asteroid paths appear to cross each other when drawn on a flat sheet of paper, collisions are impossible because the orbits are inclined at various angles and pass above or below one another. The broken lines indicate the parts of orbits which lie 'below' the plane in which the Earth moves.

soon ran out, and some of the more recent names are hardly in keeping. For instance, No. 674, discovered by a student at Drake University, is named 'Ekard' – 'Drake' spelled backwards. Asteroids with exceptional orbits are usually given male names.

DIMENSIONS. Ceres, with a diameter of 485 miles, is by far the largest of the minor planets. Pallas is 304 miles across; no other exceeds 300 miles. The brightest of the group, by virtue of its high albedo, is Vesta, which can attain the sixth magnitude and can then be glimpsed without optical aid. All the asteroids put together would form a body with a mass less than 1% of that of the Earth, and it is scarcely necessary to add that even Ceres can retain no trace of atmosphere.



Some asteriods compared with the Isle of Wight. The exact size and shape of Eros are not known, but regular fluctuations in its brilliance make it seem almost certain that it is an irregular, roughly oblong body spinning slowly.

(*From Guide to Planets, by P. Moore*)

THE TROJANS. No. 719, *Thule*, at a mean distance of almost 400 million miles from the Sun, was long regarded as the outermost minor planet; but in 1908 came the discovery of the first of the Trojans, which move in the same orbit as that of Jupiter. There are two Trojan groups, one 60° in front of Jupiter and the other 60° behind it. Thirteen Trojans are now known. The largest, *Achilles* and *Patroclus*, are over 150 miles in diameter, but their great distance makes them difficult to observe.

EARTH-GRAZERS. The so-called earth-grazing minor planets are those which have orbits which bring them well within the orbit of Mars, and thus close to the Earth. The most famous member of the group is **Eros**, No. 433, which was discovered by Witt in 1898. It is an irregularly-shaped body with a longest

Asteroids are usually discovered from photographs such as this. During the exposure, while the telescope follows the stars, the asteroid moves against the background and leaves a short trail.

diameter of 15 miles, and in 1931 it passed within 17 million miles of the Earth, proving very useful as an aid to determining the value of the **astronomical unit**. The next close approach will be that of 1975.

Other earth-grazers are *Albert* (minimum distance from the Earth 20 million miles, diameter 3 miles); *Amor* (10 million miles, 10 miles); *Apollo* (7 million miles, 2 miles); *Adonis* ($1\frac{1}{2}$ million miles, 1 mile); and *Hermes* (200,000 miles, 1 mile). The closest approach on record is that of Hermes, in 1937, when the minimum distance was 400,000 miles – less than twice the distance of the Moon. Fortunately, the chances of our being hit by a minor planet are extremely small.

Owing to the small masses of the earth-grazers, Eros excepted, their orbits are difficult to compute accurately, and several of them have unfortunately been lost.

HIDALGO. This remarkable object was discovered by Baade in 1920. It has the greatest orbital eccentricity and inclination of any minor planet, and was at one time suspected to be an unusual comet, though subsequent investigation has not borne out this view.

ICARUS. Icarus, discovered by Baade in 1948, may be regarded as an earth-grazer, since it can approach to within 4 million miles of our world. Its aphelion distance from the Sun is 183 million miles, so that it is then well

beyond Mars; but at perihelion it is a mere 19 million miles from the Sun, closer even than Mercury. The sidereal period is 400 days. Icarus experiences great extremes of temperature, and at perihelion it must be red-hot.

ORIGIN OF THE MINOR PLANETS. Olbers suggested that the asteroids were caused by the disruption of a former major planet that used to revolve between the orbits of Mars and Jupiter. This remains a possibility, even though there is no clue as to the cause of the disaster. On the other hand, it is equally possible that the asteroids never formed part of a larger planet, and in this case they may be termed the débris of the solar system.

LANDING ON A MINOR PLANET. It is clear that the minor planets are airless, lifeless worldlets. Even if they are reached in future centuries, it is difficult to see how they can be put to much use, and they are among the least interesting bodies of the Solar System. Only those with exceptional orbits, such as Icarus and Eros, are likely to engage the attention of either amateur or professional astronomers. (P.M.)

AN 'UNRIDABLE' ASTEROID. The masses of many minor planets are so small that, over most parts of their surfaces, gravitation is too weak to overcome the centrifugal force set up by their rotation. Any object placed loosely on such an asteroid would at once be gently but irrevocably flung into space and would drift away along a spiral path. Surface gravity on the asteroid ranges from slightly positive near its axis of spin to markedly *negative* on its 'equator'.

ASTRAEA. An **asteroid** with a diameter of about 60 miles.

ASTROLABE. An instrument for measuring the **altitude** of celestial bodies. In its ancient form, which goes back to the 3rd century B.C., it is a circular disc marked off in degrees along its rim and fitted with a movable arm carrying sights through which the star is viewed. When in use, it is held suspended in a vertical plane. It is now entirely replaced by the **sextant**, but its name has been adopted for a modern instrument which gives very exact measurements on firm ground.

GERMAN ASTROLABE, 16th century. Stars are viewed through the holes in the two end plates of the movable arm.

ASTROLOGY. The ancient practice of divining the course of future events from observations of celestial bodies. The planets, certain stars and the signs of the Zodiac were each considered symbolic and capable of exerting influences towards war, anger, love, etc., and their conjunctions, oppositions and other configurations at the moment of birth of a person were believed to be of great importance in casting his *horoscope.*

As a means of prophecy, astrology is entirely worthless and without foundation.

But through stimulating detailed observation of celestial motions from prehistoric times it became the parent of astronomy.

ASTRONAUTICS is the science of space flight.

ASTRONOMICAL UNIT. The mean distance of the Earth from the Sun. It is used as a unit for measuring and expressing distances within the solar system and among the nearer stars, and is equal to 92,907,000 miles according to the most recent determination. Since a larger unit of distance, the **parsec**, is based on the astronomical unit, it is most desirable that its value should be accurately known. The best results so far have been obtained from **parallax** measurements made on those **asteroids** that pass within the Earth's orbit round the Sun; artificial satellites will make further refinements possible.

ASTRONOMY can claim with justice to be the oldest of the sciences. From the earliest times men have watched the stars and wondered what they were. Living, as they did, in small communities, many of them nomadic, they were much closer to Nature than we are today. There were for them no artificial lights to brighten the skies at night and to dim the stars; the town dwellers of to-day no longer see the beauty of the heavens, the stars in all their glory.

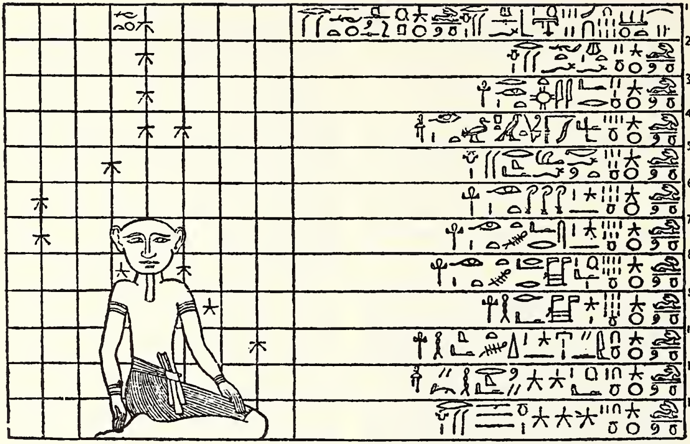
From very early times men knew the stars. They were their guides at night. They gave to many of them names; they divided them into groupings or constellations, named after animals, mythological deities, or common objects, as they thought they saw some resemblance, or as fancy took them. The names of the constellations in use to-day were mostly given about 2700 B.C. by people living in the region of Mesopotamia.

They imagined that the celestial bodies influenced their lives. The Sun, in its annual passage amongst the stars along the Zodiac, marked out the year with the alternation of the seasons and was clearly of great importance. The Moon, with the succession of its phases, was useful as the measure of a shorter interval of time; with the evolution of a priestly caste, it became general for religious festivals to be associated with the phases of the Moon. The Moon was believed to affect men in various ways and we have a survival of this belief, for instance, in the words 'lunacy' and 'lunatic'. It was not a great step further to suppose that all the other celestial bodies had some influence on human activities.

Misguided though they were in this belief, it prompted the observation of the celestial bodies, the recording of phenomena such as eclipses of the Sun and Moon, and of the times of New Moon. They found that the celestial bodies were of two types: there were the 'fixed' stars, whose positions relative to one another did not change in the course of their daily motion across the sky, nor from night to night, nor from year to year: there were also the 'moving' stars, whose positions relative to one another and to the fixed stars changed from night to night and from year to year. There were seven of these moving stars, Sun, Moon, Mercury, Venus, Mars, Jupiter and Saturn, which from early times were associated with the names of deities and to which were attributed the qualities of these deities. These moving stars or *planets* – a term whose literal meaning is a moving star – were always to be found within the belt circling the sky that was called the Zodiac. But their motions were not easy to explain nor their positions easy to predict. The search for an explanation provided the urge to observe and record. So astronomy and astrology grew up, as it were, hand in hand.

Comets, or 'hairy stars', seemed to be of a different nature. They appeared without warning and at infrequent intervals. No sort of prediction as to when a comet might appear seemed possible. A bright comet, with its flaming tail stretching far across the sky, is a magnificent spectacle; to primitive people it was awe-inspiring and came to be regarded as an ill-omen, a harbinger of disaster, of plague or flood. Possibly some bright comets had appeared at or before such happenings and had consequently given birth to such beliefs.

Three periods of time of importance to mankind were marked out by the celestial bodies: the day, with its alternation of daylight and darkness, in which the vault of heaven appeared to make a complete rotation; the lunar month, in which the Moon went through its sequence of phases; and the year, with the succession of the seasons. Attempts were early made to combine these into a calendar for the regulation of human activities,



AN ANCIENT EGYPTIAN STAR CHART of about 1800 B.C. It lists the positions of stars as they appear on a certain date relative to the figure of the astronomer's assistant who is seated a few paces north of the astronomer himself.

The chart is for the 16th day of the month of Phaophi, when in the

1st hour	the Leg of the Giant	(is) above the middle.
2nd hour	the Heel of the Giant	above the middle.
3rd hour	the star Arje	above the left eye.
4th hour	the Head of the Bird	above the left eye.
5th hour	his Tail	above the middle.
6th hour	the Thousandfold Star	above the left eye.
	. . . .	. . . .
9th hour	Orion	above the left elbow.
10th hour	the star that follows the soul of Isis (*Sirius*)	above the left elbow.

for fixing the times for the observance of religious festivals, for determining the times for the sowing of seeds and so on. But for a long while neither the length of the lunar month – which, indeed, is variable – nor the length of the year was known. The year might be marked out by the alternation of a dry period and a wet period, by the alternation of summer and winter, or by the annual flooding of a river, as of the Nile. But none of these phenomena was sufficiently regular to serve as a useful guide. The difficulty of forming a calendar lies in the fact that neither the year nor the lunar month contains an exact number of days, nor does the year contain an exact number of lunar months. The day usually began at sunset, a reminder of which we find in the account of the Creation in the Book of Genesis: 'And the evening and the morning were the first day'. The month began with the first appearance of the crescent Moon in the evening sky.

It was soon found that twelve lunar months, each recorded by the first appearance of the crescent Moon, were shorter than the year, for with this reckoning the calendar year and the seasons soon fell out of phase with one another; also that thirteen lunar months were longer than the year. To keep the year in phase with the seasons, some years were given twelve months, and others thirteen; it was usually left to the priestly caste to decide

when a thirteenth month should be added. From the accumulation of records, it was eventually found that 19 years and 235 lunar months were very nearly equal in length. This made a more regular arrangement possible in which during a cycle of 19 years, 12 years were each given 12 months and 7 years were each given 13 months, the longer years being given definite fixed positions in the cycle. From the records, it was also found that eclipses of the Sun and Moon recurred after a period of 18 years and 10 or 11 days, which was called the Saros, and used for the prediction of eclipses.

Amongst the Romans, the intercalation of the thirteenth month was left to the Pontiffs, who manipulated the calendar for their own purposes, so that by the time that Julius Caesar became Pontifex Maximus, the seasons were grossly out of phase with the calendar year. The reform of the calendar by Julius Caesar in the year 45 B.C. made the great step forward of cutting the month completely free from the phases of the Moon, giving to each month a fixed number of days (the lengths of the months then assigned being those that are still in use), and to the year a normal length of 365 days, with an extra day every fourth year. The further reform by Pope Gregory XIII in 1582 modified the rule for fixing leap years, to as to bring the average length of the calendar year into closer agreement with the true length of the year; introduced into England in 1752, it is the calendar in universal use to-day.

Primitive people, looking at the heavens, formed the idea that the number of the stars was immensely great. Their number was compared with the number of grains of sand on the seashore. This view though, as we now know, correct was surprising, for only a few thousand stars can be seen with the naked eye. When the first ideas began to be formed about the Universe, it was thought that the stars were all attached to a crystal sphere, lying just beyond the sphere which carried Saturn, the most distant of the then known planets. The revolutionary view propounded by Copernicus in 1543 – that the stars were at rest and that their apparent diurnal motions were due to the rotation of the Earth on its axis and, furthermore, that the Earth revolved round the Sun and not the Sun around the Earth – made it no longer necessary to assume that the stars were all at the same distance. It was, however, only gradually that the view came to be accepted that the stars were scattered throughout space to a great distance; it was supposed that the differences in brightness of the stars were due mainly to differences in distance and that, with increase in distance, the stars became fainter and fainter until they ceased to be visible. So men came to have a much grander view of the Universe; instead of the small compact Universe pictured by the early Greek astronomers, it was thought that the Universe might even be infinite in its extent.

The Greek astronomers made many attempts to account for the observed motions of the planets. In their view the circle was the perfect curve and their theories of the motions of the planets were all based on the assumption that it must be possible to account for these motions by a combination of circular motions. This representation was not satisfactory; as observations improved in accuracy, more and more of these circular motions had to be added and the theories became more and more artificial. Even so, this view was still held in the time of Copernicus, though he made some simplification by placing the Sun instead of the Earth at the centre of the Universe.

This Gordian knot was eventually cut by Kepler in the 16th century. Using the observations made by the great Danish astronomer, Tycho Brahe, he was able to show that the planets moved in ellipses, with the Sun in one of the foci, and in such a way that the line from the planet to the Sun traced out equal areas in equal times. This was an immense simplification. Kepler's laws of motions of the planets would appear to indicate that there must be some basic underlying reason.

But the idea that the Earth, the home of man, of man made in the image of God, was fixed at the centre of the Universe, had been accepted for so many centuries and was so firmly rooted in men's minds that the very revolutionary ideas of Copernicus were slow in gaining acceptance. The Copernican theory and the laws of Kepler they chose to regard merely as a convenient mathematical representation. It was the invention of the telescope at the beginning of the 17th century and the discoveries made with it by Galileo that slowly but surely caused the old ideas to be abandoned. Galileo found that there were

spots on the Sun, whose positions changed from day to day in a way that could be explained only by supposing that the Sun was rotating about an axis. If the Sun rotated, why not the Earth also? He discovered the four major satellites of Jupiter, and observed their changes of position night by night, which proved that they were revolving around Jupiter, analogous to the Copernican view that the planets revolved round the Sun. He showed that Venus went through a complete cycle of phases like those of the Moon, which could be explained on the Copernican theory but not on the old Greek theories.

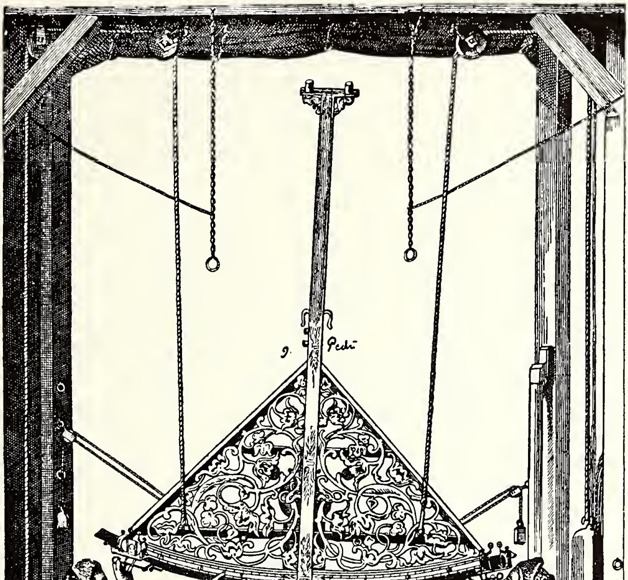
Kepler's famous three laws of planetary motion were deductions from observations. No theory was involved, and they remained uncoordinated until the genius of Newton provided an explanation by his theory of universal gravitation. He supposed that every particle of matter in the Universe attracted every other particle with a force proportional to the product of their masses and varying inversely as the square of their distance apart. By this grand unifying conception, he showed that the same force that causes an apple to fall to the ground also holds the Moon in its orbit round the Earth; the Moon instead of moving outwards into space can be thought of as continuously falling towards the Earth under its gravitational attraction. Newton showed that this same theory could account for the main phenomena of the tides, for Kepler's laws of planetary motion, and for the principal inequalities in the motion of the Moon.

> Nature and Nature's laws lay hid in night;
> God said 'Let Newton be', and all was light.
> (*Pope*)

Halley, the contemporary and friend of Newton, who had defrayed the costs of publication of Newton's immortal work, the *Principia*, felt certain that the comets must also move under the control of the Sun's gravitational attraction. With this in mind, he collected all the observational data that were available of bright comets that had appeared in preceding centuries and worked out their orbits. He hoped that a future comet would be found to be moving along the path of an earlier comet and would therefore prove to be a return of a comet that had previously appeared. Having computed the orbits of 24 comets, he found that the paths of bright comets that had appeared in the years 1531, 1607 and 1682 were so nearly identical that they must relate to one and the same comet. He therefore predicted that the comet would appear again about the end of the year 1758. As that time approached, very great interest was aroused as to whether Halley's prediction would be verified. The comet duly appeared, being first detected on Christmas Day, 1758. This most famous of all comets has become known as Halley's Comet. The success of the prediction was a triumphant vindication of the correctness of Newton's theory, which had not gained general acceptance on the Continent, where Descartes' theory of vortices was preferred. It proved moreoever that the comets, like the planets, move according to law and not by chance and that, even at the enormous distances from the Sun to which they recede in the course of their orbital motion, they are still subject to the control of the Sun's gravitation.

The paths of the Moon and the planets are not strictly ellipses because, in consequence of the universal nature of gravitation, there is mutual attraction between all the members of the solar system. The motion of any particular planet is therefore perturbed by the attractions of all the other planets, which are continually varying as their distances change. The accurate prediction of the position of any planet at a particular time is consequently not an easy matter. During the 18th century many investigations were undertaken, particularly by Laplace, who has been called the Newton of France, to account in detail for the observed motions of the planets and the Moon. For this purpose, the mass of each of the bodies involved must be found, because the gravitational attraction is proportional to the mass of the attracting body. The outcome of these and of later investigations was to show that Newton's theory of gravitation could account in detail for all the observed motions, with two exceptions: the motion of the perihelion point of the orbit of Mercury showed a small but definite discordance from theory, and there were anomalies in the observed positions of the Moon that could not be accounted for.

The explanation of these residual discordances has been found only during the present century. Though Newton had formulated his law of universal gravitation, he attempted no explanation of gravitational attraction.



Johannes Hevelius and his wife making observations with their large double octant, A.D. 1659.

By the formulation of his theory of general relativity, Einstein provided a new conception of time, space and gravitation. According to this theory, the properties of space are modified by the presence of matter; space becomes curved. The shortest path in a curved space is not a straight line. According to Einstein's theory, a planet moves round the Sun in a curved path because that is the straightest path in a curved space. But the path proves to be slightly different from that computed on the basis of Newton's law of gravitation; the difference accounts exactly for the discordance in the motions of the perihelion of Mercury. No other differences from strict gravitational theory, which are large enough to be detected by observation, are involved.

The anomalies in the observed positions of the Moon have been proved in recent years to be the consequence of slight variations in the rate of rotation of the Earth. The predicted positions are based, of course, on the assumption that the rotation, which provides our basic standard, is uniform. The variations in the Earth's rotation also produce divergences between observed and computed positions of the planets but, as the planets are at much greater distances than the Moon, the divergences are much smaller for them; it is only the improved accuracy of observation that has enabled them to be detected.

The slightly erratic time-keeping of the Earth has become of importance in recent years; time is now required with very high accuracy by the radio engineer and the physicist, for the control of precision standards of frequency. Comparisons between the observed positions of the Moon and the accurate theory of the Moon's motion now provide the required control ovei the behaviour of the Earth and enable a uniform time to be derived from the slightly non-uniform time based on the Earth's rotation.

In 1718 Halley found, by comparing current positions of stars with those observed by Hipparchus about 130 B.C., that some of the bright stars had certainly changed their positions. The stars were therefore not fixed, as had always been believed. If some are moving, all are probably moving. It was therefore no longer logical to suppose that the Sun, or any particular star, is at the centre of the Universe.

The first attempt to formulate a structure of the Universe, based on observation, was made by William Herschel about the end of the 18th century. He found it to be a much-flattened, almost disc-like structure, the Sun being near its centre. The broad belt of hazy light, stretching across the sky, called the Milky Way, consists of a vast number of faint distant stars; the Milky Way marks the great extension of the disc-like system. Herschel was unable to give any information about the dimensions of the system, for the first measurements of the distances of stars were not made until some years later.

The measurements of stellar distances, extended by various indirect methods, have provided in recent years a much more detailed and more accurate picture of our stellar system or galaxy. As Herschel showed, it is a highly flattened system extending in its central plane for about 100,000 light years. It has a central massive nucleus, in the direction of the brightest portion of the Milky Way. The Sun lies nearly in the central plane, but far out from the nucleus, at a distance of about 30,000 light years. The whole system is in slow rotation, under the general influence of its gravitation, and therefore not rotating like a solid body; the nearer to the centre, the faster is the rotation. The solar system makes one revolution around the nucleus in about 250 million years, travelling at a speed of about 150 miles a second. Along the central plane of the system there is a great deal of matter, in the form of gas and small solid particles (dust) that have not condensed into stars. This dusty matter dims or obscures the light from the stars beyond it and was responsible for Herschel's erroneous conclusion that the Sun was near the centre of the system. The total mass of the system is about one hundred thousand million times the mass of the Sun.

Observations in the last few decades have shown that our galaxy is but one of many other galaxies, extending outwards to the greatest observable distances (about 2,000 million light years), which show characteristics generally similar to those of our galaxy. They are mostly of a spiral structure, with arms spiralling out from the central nucleus. Very recently it has been established that our galaxy has this typical spiral structure and that the solar system lies in one of the spiral arms. It is estimated that there are several hundred million of these systems, their

average distance apart being a few million light years.

They are found all to be receding from our galaxy, and also from each other, the relative velocity of recession of any two being proportional to their distance apart. We may express this in another form: the whole Universe is in a state of expansion, carrying the galaxies with it. What this means is still a matter for discussion, and is dealt with in the article on **Cosmology**.

The relationship of our Earth to the Universe thus proves to be very different from the early ideas, which placed the Earth at the centre of a small Universe, and believed it to be the most important part of the Universe, around which everything else revolved. It now proves to be merely one of a system of planets, revolving around the Sun which is but one of many thousands of millions of stars comprising our galaxy. This galaxy is in turn one of many millions of galaxies scattered through space to distances beyond limits that can be reached by the most powerful telescopes yet made.

Because astronomy has been able to tell us so much about the nature and vastness of Creation, it can be called the queen of the sciences. It has an inherent appeal to the human mind. We, on our little Earth, endeavouring to plumb the remote depths of space, cannot but feel humble at the insignificance of our home, the Earth, in the vast scheme of things. Many questions instinctively come to our mind, which remain as yet unanswered. How did the Universe begin and how will it end? Or has it existed through the infinite past and will it continue to exist for an infinite future? Was there an initial act of creation, or is creation a process that is continuously operating, new matter being created, from which stars and galaxies will form? If there is no continuous creation, we should eventually appear to be alone in space, for one by one the galaxies, by the process of expansion, will pass beyond the range of observation. What is man's place in the Universe? Is there life on other worlds and, if so, may it possibly have developed into forms much higher, much more intelligent, much more competent than man? Everywhere in the Universe, we find evidence of law and order: chance plays no part in its evolution. Is this evidence for a Divine Creator and for divine control?

There is much that we should like to know. There is much for the astronomers of the future to investigate. At present we can say, with St. Paul, that we see as through a glass darkly. And as we look, awed and mystified, we cannot but echo the words of the Psalmist 'What is man, that Thou art mindful of him?' (H.S.J.)

ASTROPHYSICS. The application of the laws and principles of physics to all aspects of stellar astronomy.

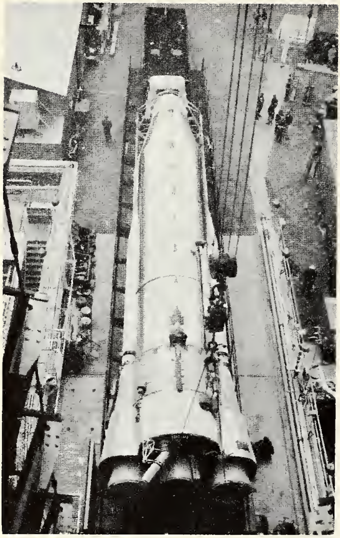
Astrophysics embraces so large a part of astronomy that its component topics are inevitably scattered through the pages of this volume. We indicate below the headings under which these topics will be found.

The method by which the physical conditions which obtain near the surface of a star may be deduced from a study of its light is described in the article on **Spectroscopy**. Certain characteristics of this light determine the **Spectral Classification of Stars**. The mass and radius of a star, and sometimes other interesting information, may be found directly in some cases, principally those of the **Binary Stars**. From the knowledge so acquired it is possible to hazard a guess as to the conditions and processes inside the star, where it is forever impossible to make direct observation. The two main sources of energy in stars are the *carbon-nitrogen cycle* and the *proton-proton process*, which are described under **Stellar Energy**.

The scales that are applied to the measurements of a star's brightness are given under **Magnitude** and **Bolometric Magnitude**. The **Astronomical Unit**, the **Parsec** and the **Light Year** are units commonly employed to express distances, and are compared in a table under **Distances, Astronomical**; the article on **Parallax** should also be read in this connection.

Under **Star** the methods are described by which stellar masses, densities, gravitational fields and rotations are found. **Proper Motion** deals with the *apparent* movement of stars on the celestial sphere; their *true* motions are discussed in **Stars, Motions and Distances**.

Having learnt about stars individually, we can attempt to fit them into a pattern and see if any conclusions can be drawn about their evolution and development. The most promising pattern is the **Hertzsprung-Russell Diagram**, from which the notion of *Main Sequence* is derived. (R.G.)



ATLAS. A view of the missile from the gantry prior to erection. The picture shows the two booster engines on either side and the angled exhaust of the fuel turbopump.

ASYMPTOTE. A (usually straight) line which approaches nearer and nearer to a curve without ever touching it. See fig. under **hyperbola**.

ATLAS. An American inter-continental ballistic missile which has been successfully tested over its full range of 6,500 miles. On December 18, 1958, an *Atlas* was placed in orbit round the Earth. It is being superseded by **Minuteman.** (For details, see **Missile** and **Artificial Satellite.**)

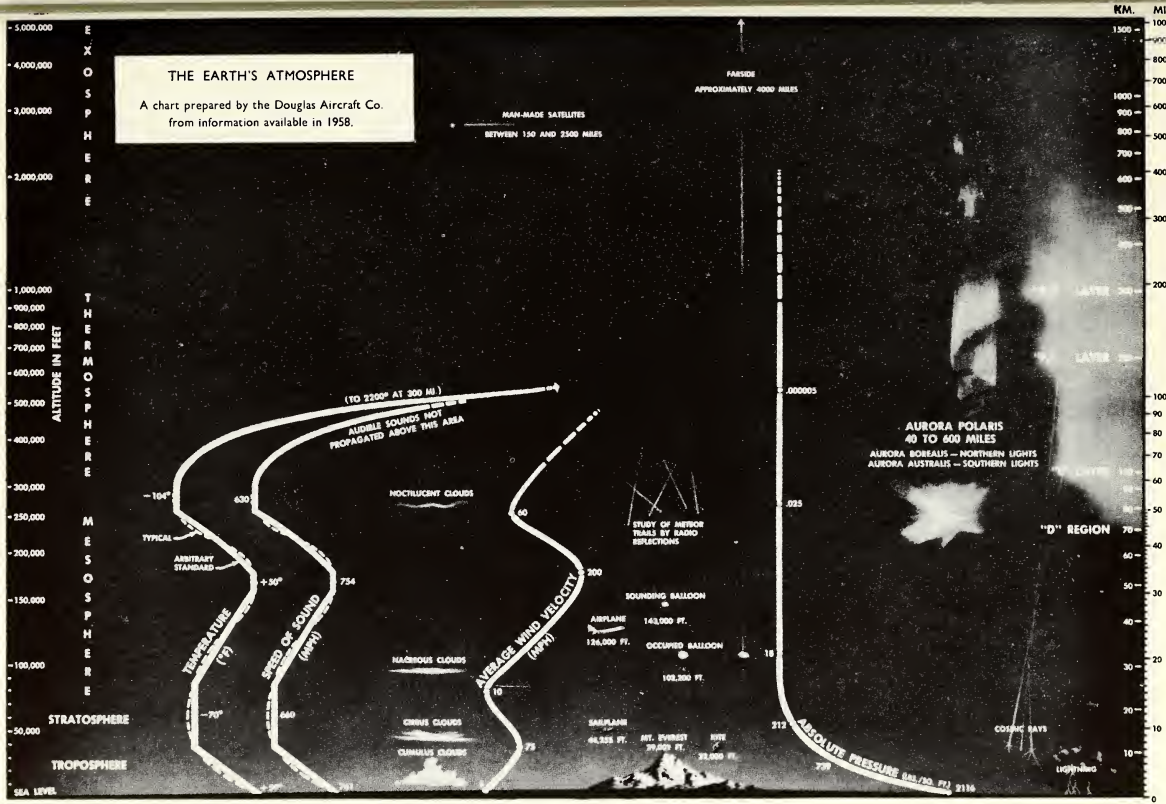
ATMOSPHERE. The gaseous envelope surrounding a star, planet or satellite. Whether such a body can retain an atmosphere permanently depends chiefly on its mass, size and surface temperature. The molecules in a gas are in constant random agitation, and their average speed increases with increasing temperature. At any moment, a proportion of these molecules will be moving away from the surface of the body, and those whose speed is greater than the **escape velocity** for that particular star or planet will leave it altogether and drift into interstellar space. Thus a small, light body will constantly lose some of its atmosphere unless its surface is so cold that virtually no molecules can reach escape velocity.

A more massive body may actually increase its atmosphere by the reverse process of *accretion*. As it travels through space, it sweeps up interstellar matter by its gravitational attraction, and this will be added to its atmosphere.

The atmosphere of the Earth is described in the following article, and that of the various planets under their names. Only one satellite in the solar system – Saturn's Titan – is definitely known to have an atmosphere. It consists mainly of methane, a poisonous gas often used as a rocket propellent. It has been suggested that this methane might be used to refuel rockets, but it is probable that by the time Titan can be reached, such propellents will be obsolete.

For those stars that consist largely or wholly of gases, the word atmosphere can have no precise meaning beyond referring loosely to the surface layers. Hydrogen is by far the most abundant element in these layers; helium is common, and neon, oxygen and nitrogen are usually found in varying amounts and states of ionization. There are, however, some interesting extremes: the atmospheres of **white dwarfs** are probably only a few feet thick, the tremendous gravitational pull of these stars compressing matter below that depth into a state which can no longer be called gaseous. (See **degenerate matter** and **critical temperature.**) Some very hot O and B type stars have, by their rapid rotation, thrown off gases which form a shell surrounding the star. Such a shell is known as an *extended atmosphere*; it rotates independently and more slowly about the central part of the star.

ATMOSPHERE OF THE EARTH. A thin envelope of gases surrounding the Earth. Its approximate composition by volume is: nitrogen, 78%; oxygen, 21%; argon, 0.94%; carbon dioxide, 0.03%; hydrogen, 0.01%;


THE EARTH'S ATMOSPHERE
A chart prepared by the Douglas Aircraft Co. from information available in 1958.
ALTITUDE IN FEET
EXOSPHERE
THERMOSPHERE
MESOSPHERE
STRATOSPHERE
TROPOSPHERE
SEA LEVEL
KM.
MI.
MAN-MADE SATELLITES
BETWEEN 150 AND 2500 MILES
FARSIDE
APPROXIMATELY 4000 MILES
(TO 2200° AT 300 MI.)
AUDIBLE SOUNDS NOT PROPAGATED ABOVE THIS AREA
TEMPERATURE (°F)
SPEED OF SOUND (MPH)
AVERAGE WIND VELOCITY (MPH)
ABSOLUTE PRESSURE (LBS./SQ. FT.)
TYPICAL
ARBITRARY STANDARD
NOCTILUCENT CLOUDS
NACREOUS CLOUDS
CIRRUS CLOUDS
CUMULUS CLOUDS
STUDY OF METEOR TRAILS BY RADIO REFLECTIONS
SOUNDING BALLOON
143,000 FT.
AIRPLANE
126,000 FT.
OCCUPIED BALLOON
102,200 FT.
SAILPLANE
46,255 FT.
MT. EVEREST
29,002 FT.
KITE
22,000 FT.
AURORA POLARIS
40 TO 600 MILES
AURORA BOREALIS — NORTHERN LIGHTS
AURORA AUSTRALIS — SOUTHERN LIGHTS
"D" REGION
COSMIC RAYS
LIGHTNING

neon, 0.0012%; helium, 0.0004% and minute traces of other rare gases. In addition, there are varying amounts of water vapour.

The weight of the atmosphere creates a pressure at sea-level of about 14.7 lbs. per square inch (= 1 Atmosphere or 760 mm. of mercury). At first, the temperature falls with increasing height, but at about 38 miles it rises suddenly to 200° F. At 52 miles it has fallen once more to —150°, and above that it becomes warmer again.

ATMOSPHERIC ABSORPTION. The Earth's atmosphere is transparent to visible light, but it absorbs most other frequencies of the **electro-magnetic spectrum**, including the X-rays and most of the ultraviolet and infra-red radiation emitted by the Sun. Without this cushioning effect of the atmosphere, the Sun's rays would make the Earth's surface unbearably hot and destroy life on it. But to astronomers, and especially to spectroscopists among them, this partial opaqueness of the atmosphere means that large parts of stellar spectra cannot be studied from within the atmosphere. Photographs taken by cameras in high altitude rockets have already considerably extended our knowledge of the solar spectrum, but the much fainter radiations from stars and the planets require prolonged and carefully controlled exposures; artificial satellites provide opportunities to take these.

There are two 'windows' in the atmosphere, the first ranging from the very 'softest' ultraviolet through the visible spectrum into the infra-red (radiated heat); the second covers the shorter radio waves, and it is this window through which **radio astronomy** looks for new knowledge of the stars. (See also **Electromagnetic Spectrum**.)

SCATTERING. The molecules in the air scatter the sunlight in all directions, but the bluer part of the light is affected most. As a result, the Sun appears more yellow to us than it really is, its direct rays having lost a higher proportion of the blue frequencies which have been scattered throughout the sky and give it its colour. At an altitude of 100 miles the air is already too tenuous for this effect to be noticeable, so that there the Sun appears almost white, the sky black, and the stars are clearly visible against the dark background.

The atmosphere is subject to **tides** in the same way as the water layer of the Earth, but the effect is completely overshadowed by the random changes in the weather at ground level.

At about 60 miles the high altitude winds stream around the Earth at speeds of some 130 m.p.h. They are probably caused by the unequal heating of the atmosphere on the day and night sides, and are remarkably steady but contain much turbulence. (See also **refraction.**)

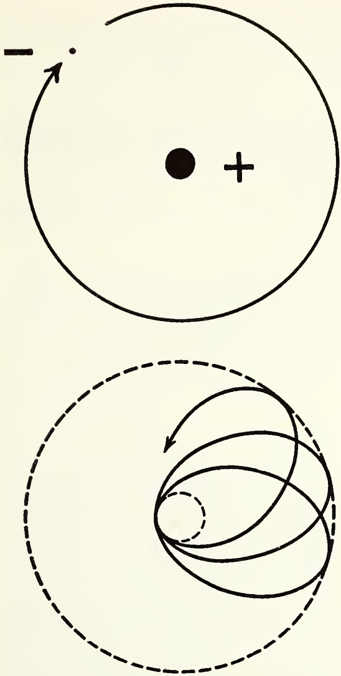
Observations by artificial satellites have shown the atmosphere to be far more extensive than was previously thought. The lower ionosphere was found to be warmer over the polar regions than elsewhere.

If the extent of an atmosphere were defined as the distance at which its density falls to that of interplanetary matter between, say, Mars and Saturn, then the Earth may be within the atmosphere of the Sun.

ATOM. The smallest unit of a chemical **element** which retains the chemical characteristics of that element. Atoms were originally thought to be hard, indivisible particles, but they are now known to be more like miniature solar systems.

At the centre of an atom is the *nucleus*, compounded mainly of *protons* with a positive electrical charge, and of *neutrons*, which are similar but have no charge. For each proton there is an *electron* which circles about the nucleus. The mass of a proton is almost two thousand times that of an electron, but the negative electrical charge on an electron is equal in strength to the proton's charge. Since their numbers are equal, the total charge of an atom is nil, but if electrons are removed (or added) the resulting *ion* will have excess positive (or negative) charge.

In a planetary system, gravitational forces are the most important; in the atom, they are completely overshadowed by the electrical forces. An atom is a very empty affair. The simplest atom is that of hydrogen, where one electron circles about one proton. Let a pea represent the proton, then the electron would be a grain of salt revolving about it in an orbit that could enclose a large building. The actual diameter of such an atom is about one ten-millionth of a millimetre, and its mass 1.6710^{-24} grams.



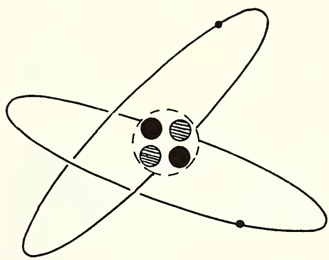
THE HYDROGEN ATOM in which a single electron with a negative electrical charge revolves about a positively-charged proton. The electron's path is shaped like a rosette.

The electrons are distributed around the nucleus in shells or layers. Each shell can accommodate a certain number of electrons, and the chemical character of an atom is chiefly determined by the number present in the outermost shell.

An atom may absorb energy, e.g. in the form of light. This energy can make an electron jump from one orbit into another of greater radius, and it can be released again as radiation when the electron jumps back into a smaller orbit. There are many possible orbits, and each particular change of orbit corresponds to the emission or absorption of radiation of a particular wavelength. When many atoms of an element undergo such changes at the same time, a variety of wavelengths will be involved which will all show up in the emission or absorption **spectrum** of the element.

Excessive absorption of energy by an atom may lead to the detachment of one or more electrons, i.e. ionization. Atoms may also combine with each other to form *molecules*, whose chemical and physical character will differ markedly from that of the original atoms.

The *ground state* of an atom is that in which it can absorb but not emit energy because its electrons are already in the smallest available orbits. Each absorption of energy will transform the atom into a higher state or *energy level*. When an atom moves as a whole, it also possesses (like any other moving object) **kinetic energy**.



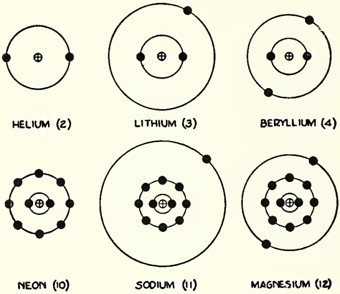
THE HELIUM ATOM: two protons and two neutrons form the nucleus; two electrons travel in orbits around it. The nucleus of the helium atom without the electrons is known as an alpha particle.

This simplified discussion should not be taken too literally. It is an attempt to state in simple language what can be accurately described only in mathematical terms. (M.T.B.)

ATOMIC ENERGY. See **Nuclear Reactions.**

ATOMIC NUMBER. The number of protons in the nucleus of an **atom.**

ATOMIC WEIGHT. The number of times that a given **atom** is heavier than one atom of hydrogen is called its atomic weight. It is a ratio, and quite distinct from the actual weight in grams of the atom. (More recently, oxygen = 16 has been substituted as the standard, which makes the atomic weight of hydrogen = 1.008.)



Electron shells of some of the lighter elements, with their atomic numbers. Details of the nucleus are not shown.

AURORA POLARIS, also called *Aurora Borealis* or Northern Lights, and *Aurora Australis* or Southern Lights, are glows in the atmosphere at a height of 40–200 miles and higher, often brilliantly coloured. They are caused by streams of electrically charged particles emitted by the Sun striking the upper atmosphere, and since the charged particles are attracted towards the Earth's **magnetic poles**, auroral displays are seen mainly in polar or at least high latitudes. Outbursts of solar flares generally lead to increased auroral activity after a definite time interval, from which the speed of the emitted particles may be calculated. (See also **Van Allen Belts**.)

AZIMUTH. The horizontal direction or *bearing* of a heavenly body calculated from the North or South points of the observer's horizon.

B

BACK-OUT. Procedure for the organized reversal of a **count-down** when the launching of a missile has to be postponed.

BAILLY. The largest **crater** on the visible side of the Moon. It has a diameter of over 170 miles.

BAILY'S BEADS. When the Moon eclipses the Sun, just before the moment of totality the crescent Sun will break up into a string of light patches called *Baily's Beads*. They represent the last direct rays of sunlight to penetrate between the irregularities of the lunar surface, and reveal the exact shape of the mountains at the Moon's edge. The beads disappear almost at once, but are seen again at the west limb after totality.

BALLISTICS. The science that deals with the motion of projectiles. *Interior ballistics* deal with the propulsion of the projectile, and *exterior ballistics* with the path it follows when it is not guided.

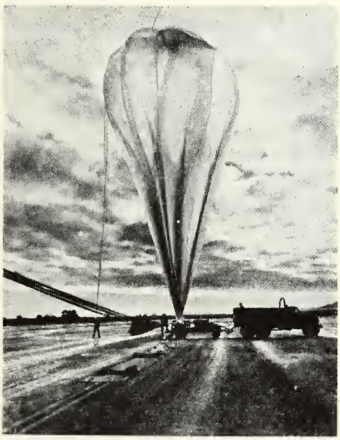
The exterior ballistician is concerned with the forces acting upon the projectile when it is moving freely by its own momentum, especially the gravitational force, wind gusts, air resistance, rolling and tumbling of the projectile, and the effects of the rotation of the Earth (see **Coriolis Force**). Short range projectiles move in parabolic trajectories modified by air resistance, but for long range projectiles the changing distance from the Earth's centre causes changes in the force of gravity and turns the trajectory into a portion of an ellipse having the centre of the Earth at one of its foci.

By working backwards from the target to the launching site the ballistician can calculate the required launching characteristics such as the muzzle velocity, elevation and deflection in the case of a gun, or the all-burnt velocity, distance from launching pad and direction of motion in the case of a rocket.

A ballistic missile is one which travels through most of its trajectory without guidance or continued propulsion.

BALLOONS. Flexible bags inflated with a gas lighter than air. If the weight of the balloon is less than that of the air it displaces, it will rise under its buoyancy. As it gains in height, the atmospheric pressure drops and with it the density of the air, while the gas inside the balloon expands. A stage will be reached when the balloon cannot expand further without bursting; it then displaces a maximal volume of air whose weight decreases as the balloon ascends further, and when this weight is equal to that of the balloon no further ascent is possible.

Heights of over 130,000 feet have been reached by instrument-carrying *Skyhook* balloons. Information from the instruments is transmitted by radio to the ground station. After a few hours the instruments are automatically dropped by parachute. The balloon then rises further until it bursts. Observations in the upper air can thus be made more economically and over longer periods than is possible with rockets.



A METEOROLOGICAL BALLOON filled with hydrogen gas; the sleeve on the left is sealed off, and strands of wire which support the recording instruments are seen running towards the furled-up parachute at the base of the balloon. The plastic skin will tighten as the hydrogen expands in the reduced pressure at higher levels.

Meteorological balloons are released so that from close observations of their ascent estimates can be made of the winds at different heights.

The pressurized gondola of a *Skyhook* balloon. Ascents to 100,000 feet have been made with manned gondolas such as this, and instruments alone have been carried even higher.

BALMER SERIES. A series of lines in the spectrum of the hydrogen atom. Each line corresponds to a transition beginning or ending in the second energy level of the hydrogen atom. See **Spectroscopy**.

BAND SPECTRUM. An emission or absorption spectrum consisting of a number of bands, each band being a very large number of closely spaced lines which overlap on low-dispersion spectrograms. Band spectra are produced by the rotation and vibration of the nuclei in molecules. See **Spectroscopy**.

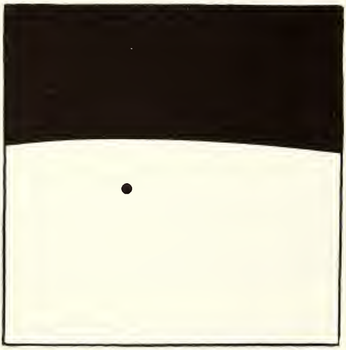
BAROMETER. An instrument for measuring the atmospheric pressure. A mercury barometer may be made simply by filling a long glass tube, sealed at one end, with pure mercury, and then inverting it with the open end placed in a small trough. Mercury will run out of the tube until a column about 76 cm. long remains. The pressure of the **atmosphere** acting on the surface of the mercury in the trough will then balance the pressure of the

column, and will prevent more mercury from running out. Changes in the atmospheric pressure can be measured by noting the change in the length of the columns. Mercury is used because a lighter liquid would require a longer tube.

The *aneroid* barometer is essentially an airtight, evacuated box with elastic sides. A drop in the outside pressure will allow the sides that have been pressed inwards to relax a little, and this movement can be magnified and observed by means of a pointer linked to the moving part. Aneroids are small, light, sensitive and portable, but cannot measure very low pressures.

BETA PARTICLE or *Beta Ray*. A fast electron emitted by certain radioactive atoms.

BETELGEUSE, the second-brightest star in the constellation **Orion**, is a relatively cool **supergiant** and one of the largest stars known. It is 1,200 times as bright as the Sun, 24 million times as voluminous, about 15 times as massive and half as hot. Its brightness varies somewhat irregularly in cycles of a few hundred days, and also its size.



BETELGEUSE AND THE SUN COMPARED. The white area represents part of the supergiant; the small black circle is our Sun, drawn to the same scale. The density of Betelgeuse is extremely low, and it has been aptly described as 'a red-hot vacuum'. It is in sharp contrast to the White Dwarfs, which are extremely small and up to a million million times as dense.

BIELA'S COMET was discovered in 1772. It returned five times, and its disruption was witnessed during its return in 1846 and is described under **Comets.**

BIELIDS. See **Andromedids.**

BIFURCATED LAYER. The E layer of ions in the **ionosphere**, which sometimes splits into two layers about nine miles apart.

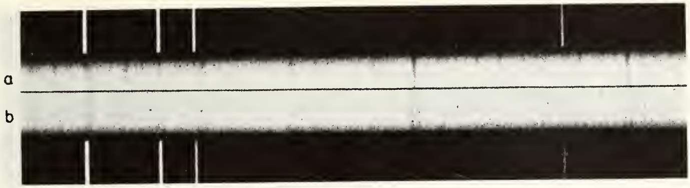
BINARY STAR, MULTIPLE STAR. A binary star consists of two component stars which revolve about their common **centre of gravity**. A multiple star is a system of more than two components.

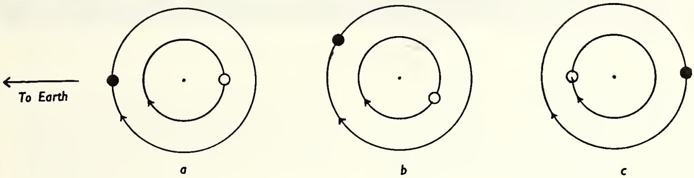
As the separation of the components of a binary (or multiple) star is in general very small compared with the distance of the system from the Earth, the components appear very close together. In very few cases is the angular separation of the two stars great enough for them to be seen individually by the naked eye; the eye cannot resolve two points closer together than about three minutes of arc, or one tenth the visual diameter of the Moon. A telescope reveals that many stars are double. The proportion of double stars with separations greater than ten seconds of arc even is quite small; many are less than one second apart.

It is possible for two stars at very different distances to lie in almost the same line of sight, giving what is known as an *optical double*. But the vast majority of double stars are true binaries in one physical system.

Binaries are very common indeed amongst the stars, at any rate in our neighbourhood of the galaxy: of the 254 stars known to be within ten parsecs of the Sun (counting each star separately) 127 are members of 61 binary or multiple systems.

Binary stars are of great use in that they enable the masses of stars to be calculated; they are the only stars whose masses can be reliably determined. We need to know the sizes of the orbits of the two stars, and the period of revolution in order to find the mass of each star. Unfortunately it is difficult to measure the positions of both components relative to their common centre of gravity and so get both orbits; usually the brighter component is regarded as fixed and the orbit of the fainter one measured relative to it. Such an orbit allows the total mass to be





found, but not the individual masses. Further difficulties present themselves: the real size of the orbit in miles, not its apparent size in seconds of arc, must be known, and this involves measuring the **parallax** of the star to find its distance. Also, to achieve accuracy, the binary must be watched over a whole period; but periods often run into hundreds or thousands of years. For the period to be short, the stars must be close together, and in order to be resolved by a telescope and to have a measurable parallax they must also be comparatively close to us. Only about 50 binaries have both well-determined orbits and well-determined parallaxes. Even when the masses have been obtained, they may not be representative of star masses as a whole. The masses of close visual binaries near to us are not necessarily typical of all stars everywhere. This is an example of the ever-present problem of *observatorial selection.*

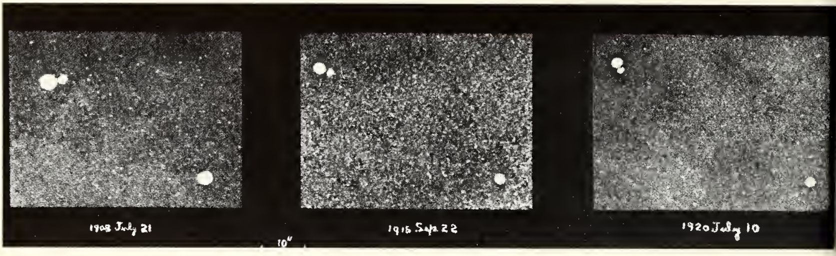
In *visual binaries* the individual components can be observed directly with the telescope. *Eclipsing binaries* are detected by their rhythmical fluctuations in brightness. *Spectroscopic binaries* are recognized from examination of their spectra.

SPECTRUM OF A SPECTROSCOPIC BINARY STAR. The example here is Mizar, which has a period of 20.5 days. (a) June 11, 1927. Both components moving at right angles to the line of sight, spectral lines superimposed. (b) June 13, 1927. One component is moving towards and the other away from the Earth; their spectral lines therefore undergo Doppler shifts to the left and to the right respectively. When the positions indicated in (c) are reached, the spectral lines will again be single. The components revolve about the common centre of gravity.

The top and bottom spectra are comparison spectra obtained in the laboratory.

(*Mount Wilson – Palomar*)

SPECTROSCOPIC BINARIES. In many binaries the separation of the components is too small to be resolved by even the largest telescope, but the spectroscope may still reveal their double nature. The orbital motion of the components will cause differences in their velocities relative to the Earth, and this will give rise to a difference of **Doppler shift** in the light from each component. If they are about equally bright, the spectroscope will show two spectra whose lines are slightly displaced relative to each other. If the components are so unequal that the light from one drowns the spectrum of the other, the duplicity may yet be indicated by a periodic oscillation in the positions of the spectral lines, corresponding to the period of revolution of the stars.



KRUEGER 60, a visual binary star. These three photographs, taken in 1908, 1915 and 1920, show the two components slowly circling each other, obedient to the same laws that govern all motion throughout the universe. – A third component of the system does not appear on the plates.

(*Barnard, Yerkes Observatory*)

The spectroscope can, however, tell us nothing if the orbit happens to lie in the plane perpendicular to the line of sight, i.e. if the *inclination* is practically 90°: the line-of-sight or **radial velocities** of the stars are then both zero, and the Doppler shift can only measure radial velocities.

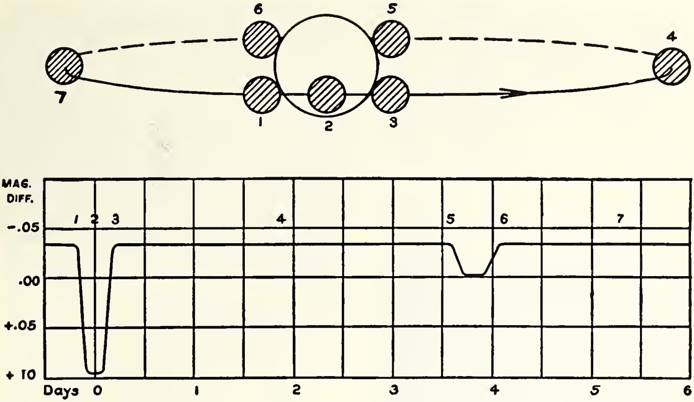
Spectroscopic binaries have periods of days rather than years (the velocities involved in the case of binaries with periods of years are so low that the spectroscope cannot readily detect them). The period of revolution is easily found, and the shape of the orbit can be inferred from a number of determinations of radial velocity at intervals throughout the period. But unless further information is available the inclination of the orbit remains unknown and so therefore its size; results of some value are nevertheless obtained in such cases by using a statistical mean value for the inclination.

ECLIPSING BINARIES can provide this additional information. About nine per cent. of all spectroscopic binaries have orbits with sufficiently small inclinations to cause each component to eclipse the other once per revolution. For these stars a whole new range of information may be derived from the manner in which their brightness varies. The variation is plotted against time on a graph known as a *light curve*.

The eclipses may be total, annular, or partial; characteristic light curves are shown in the figures. Once in each revolution there is a *primary minimum*, and there may or may not be a *secondary minimum* when the star which was eclipsed during the primary minimum passes in front of its companion. When the eclipses are total or annular, or nearly so, a good estimate of the inclination of the orbit may be made. Coupled with spectroscopic evidence this yields the **eccentricity** and size of the orbit. The radii of the components and their relative brightness may be derived from the light curve. In some cases, light from the brighter component is reflected in the fainter: the total brightness of the two rises slightly as the brighter one moves towards us after being eclipsed and shines on more and more of the side of its dull companion which is turned towards us. There is a small secondary minimum as the bright component eclipses the fainter.

In some stars, the edge of the disc or *limb* is darker than the centre, and if such a star suffers an annular eclipse, more light is obscured when the eclipsing body is in front of the centre of the disc, i.e. in the middle of the annular phase, than at the beginning and end of annularity. This gives the minimum a characteristic shape.

Another effect deducible from the light curve is the tidal distortion of close components into ellipsoid shapes; the brightness is then never stationary owing to the constantly changing area of the stars presented to us.

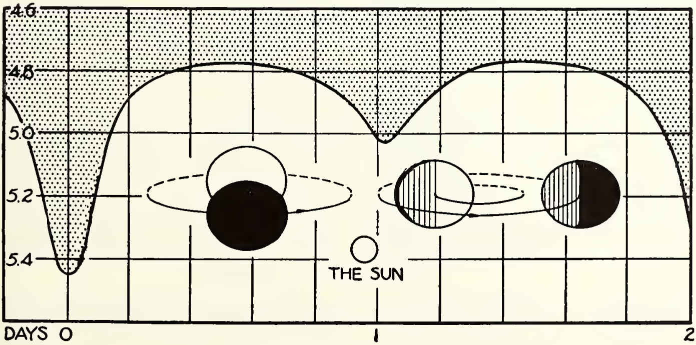


LIGHT CURVE OF AN ECLIPSING BINARY. The numbers on the graph correspond to the positions occupied by the smaller, fainter component relative to its larger companion as seen from the direction of the Earth. Between positions 5 and 6 the smaller star suffers total eclipse.

(*After Stebbins*)

Below: the light curve of u Herculis, a tidally distorted eclipsing binary. The primary minimum occurs when the brighter component is partially eclipsed. Throughout the cycle, the aspect of the elongated stars changes from broadside on to end on, and their illumination of each other alters, so that the curve is nowhere level, and the two maxima are slightly unequal. The size of the Sun is indicated for comparison.

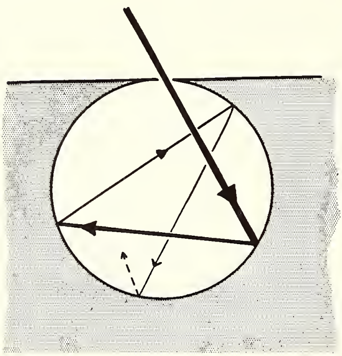
(*After R. Baker*)



If a component of an eclipsing binary is spinning about an axis well inclined to the line of sight, one limb will be turning towards the Earth while the other is turning away from it. Just before total eclipse only one limb of the eclipsed star is visible, and if the rotation is rapid enough its period may be estimated by measuring the resulting Doppler shift.

A different aspect of eclipsing binaries is discussed under **variable stars.** (R.G.)

BLACK BODY. An ideal body which absorbs all radiation that falls on it and reflects none. (See **electromagnetic spectrum.**) An object which looks black, e.g. a piece of black paper, absorbs most of the visible radiation, but it may reflect a considerable portion of the ultra-violet and infra-red (heat) rays. Perfectly black bodies in the technical sense do not exist; the nearest approach is an almost completely enclosed cavity in an opaque object. The reason for this is that any ray entering the hole may not be entirely absorbed when it first strikes the wall of the cavity, but that fraction of it which is reflected will strike the wall again elsewhere, will itself be partly absorbed and partly reflected, and so on. At each reflection more of the ray is absorbed until the unabsorbed fraction is infinitesimal. If the opening of the cavity is small enough, the chances of any reflected ray escaping through it before being absorbed are very small.



A hole acting as a black body absorber of heat. At each reflection more of the incoming heat ray is absorbed by the walls of the cavity.

If a black body is heated in any way, it will radiate heat better than any less black body, and in strict accordance with **Stefan's Law**; moreover the distribution of the radiated energy over the spectrum will obey another fundamental equation called *Planck's Law*. We can measure the distribution and amount of radiated energy received from the stars. If a star is a perfect radiator, i.e. a black body, or if we know exactly to what extent it differs from a black body, the above laws then enable us to calculate its temperature. (M.T.B.)

BLACK DROP. This is the name given to a curious phenomenon seen during a transit of **Venus.** As Venus draws in front of the Sun, it appears to draw a strip of blackness after it; when this strip disappears, the planet is found to be full on the solar disc. It is therefore impossible to give an accurate estimate of the exact moment of the start of the transit, and the Black Drop reduced the precision of the results obtained for the astronomical unit in 1874 and 1882 (see **Transits**).

BLACK KNIGHT. A British intermediate-range ballistic **missile.** Although used primarily for research and development, it is one of the most reliable of modern rockets.

BLACK-OUT. A temporary fade-out of vision experienced by pilots and others when under the stress of strong **acceleration** or retardation. It can be largely avoided by correct body posture relative to the acceleration. See **Space Medicine.**

BLOOD-BOILING. One of the consequences of subjecting the body to very low atmospheric pressure. A reduction of pressure lowers the boiling point of liquids. Water, for instance, will boil at room temperature at a pressure of 18 mm. The atmospheric pressure at a height of 12 miles is so low that the normal body temperature will exceed the boiling point of the body fluids, with fatal results. See **Space Medicine.**

BLOODHOUND. British surface - to - air guided **missile.** It has a homing device supported by boosters.

BLUE STREAK. A British long-range ballistic **missile**, fired from underground launching sites. With **Black Knight** mounted on top it will provide a launching vehicle for British satellites.

BODE'S LAW. This interesting numerical relationship was first noticed by Titius of Wittenberg, but was brought into prominence by Bode in 1772, and is hence known as *Bode's Law*.

Take the numbers 0, 3, 6, 12, 24, 48, 96, 192 and 384, each of which (apart from the first two) is double its predecessor. Add 4 to each. Taking the Earth's distance from the Sun as 10, this second series gives the distances of the other planets, to scale, with remarkable accuracy, as is shown by the following table:

Planet	*Distance by Bode's Law*	*Actual Distance*
Mercury	4	3.9
Venus	7	7.2
Earth	10	10
Mars	16	15.2
Ceres	28	27.7
Jupiter	52	52.0
Saturn	100	95.4
Uranus	196	191.8
Neptune	—	300.7
Pluto	388	394.6

The Law breaks down for Neptune, and the Bode distance corresponds much more closely to that of Pluto; but when the Law was announced, Uranus, Neptune and Pluto were unknown. Nor was there a known planet corresponding to the distance 28, and the discovery of Ceres, the largest of the asteroids, was regarded as an extra verification of the rule. It is still uncertain whether Bode's Law is fundamental, or is due purely to chance.

BOHR THEORY. The theory, due to Bohr in 1913, explaining the spectrum of the hydrogen atom. See **Spectroscopy.**

BOLIDE. A fireball or bright meteor which explodes in the course of its flight through the atmosphere. See **Meteor.**

BOLOMETER. A very sensitive kind of thermometer used for measuring weak heat radiation. A thin strip of platinum foil is coated with finely divided 'black' platinum, so that it becomes virtually a **black body.** It is carefully screened from all radiation except that which is being measured, and a weak current is passed through it and through a **galvanometer.** Any radiant heat absorbed by the strip will raise its temperature and thereby lower its electrical resistance, and the increased flow of current can be detected by the galvanometer.

BOLIDE. An exploding Andromedid **meteor.**

BOLOMETRIC MAGNITUDE. If a **bolometer** is joined to a spectroscope, the distribution of energy radiated in the infra-red region of the spectrum of the source can be measured. From this, and by an application of the **Stefan-Boltzmann Law**, a star's total emission of energy may be calculated. According to this quantity, a star is given a *bolometric magnitude*, and the scale has been arbitrarily adjusted so that for the Sun the visual **magnitude** is equal to the bolometric magnitude. For nearly all other stars, the bolometric magnitude is *less* than the visual magnitude, i.e. a *greater* part of their total radiated energy lies outside the visible range than in the case of the Sun.


THE MATADOR IN ROCKET-ASSISTED TAKE-OFF. The launching trailer appears at the end of the exhaust of glowing gas in the first picture. In the second, the booster rocket, still firing, is dropping off while the Matador proceeds on its way, powered by its own jet engine.

BONN DURCHMUSTERUNG. A vast survey and atlas of the sky listing 324,198 stars and their apparent brightnesses. It was compiled for the **epoch** 1855, and various additions were made at later dates. A star is often referred to by its B.D. number.

BOOSTER. A rocket or other propulsion unit which assists in the take-off and early acceleration of a missile or aircraft, and then drops off.

BRAKING ELLIPSES. By following a path known as a series of *braking ellipses*, a rocket returning to Earth or attempting to land on a planetary body may shed its speed without using fuel for braking, provided there is an atmosphere.

On its first approach, the missile grazes the outer part of the atmosphere, where some of its speed will be lost through friction and turned into heat. Before the hull is heated to a dangerous extent the missile is carried out of the atmosphere again in an elliptical orbit, cooling off in the very low temperatures of interplanetary space before entering the atmosphere once more. The process is repeated, and on each circuit the rocket loses speed and describes a smaller ellipse, until finally its speed is so small that the landing can be made by gliding, parachute, or with a very moderate expenditure of fuel.

If such a missile entered the atmosphere too far or for too long at full speed, it would melt and even be vapourized within seconds by the heat of friction. A small departure from the calculated braking ellipses could therefore have fatal results, and some fuel would still be required to guide the vessel into the right path and to correct minor deviations from it. Before such a method could be used on a planet, **planetary probes** would have to obtain precise data of its atmosphere by single grazings, or by telemetering a continuous record of their own destruction as they penetrated deeper. (M.T.B.)

BRITISH ASTRONOMICAL ASSOCIATION. The B.A.A. was founded in 1890 and now has a membership of over two thousand; it is open to all persons interested in astronomy. It has as its objects the association of observers, particularly the possessors of small telescopes, for their mutual help and organization in the work of astronomical observation; the circulation of current astronomical information; and the encouragement of a popular interest in astronomy. Monthly meetings are held at the rooms of the **Royal Astronomical Society** in Burlington House, Piccadilly, London, W.1. *Secretarial address:* 303, Bath Road, Hounslow West, Middlesex.

BRITISH INTERPLANETARY SOCIETY. Founded in 1933, this society now has about 3,000 members. It holds lecture meetings and publishes a bi-monthly journal devoted to technical aspects of astronautics, as well as a popular magazine entitled *Spaceflight. Address:* 12, Bessborough Gardens, London, S.W.1.

BUMPER-WAC. A high-altitude research vehicle built by the General Electric Co. consisting of a modified German V–2 rocket used as a boostei for an American **WAC Corporal.** This was the first successful two-step rocket and achieved a record altitude of 244 miles in 1949.

C

c. The symbol used to denote the velocity of light *in vacuo*. This velocity is very nearly 3×10^{10} cm. per second (186,000 miles per second). It is a fundamental constant and is the maximum velocity theoretically attainable.

CALLISTO. The fourth satellite of **Jupiter.** It is the largest of the Jovian attendants, with a diameter of 3,220 miles, but has the very low density of 1.3 times that of water; since the escape velocity is only 0.9 miles per second, there is no possibility of its retaining an **atmosphere.**

CALORIE. The amount of heat required to raise the temperature of one gram of water through one degree Centigrade (from 14.5° to 15.5°).

CANALS, MARTIAN. In 1877, Schiaparelli drew attention to certain narrow, linear features on Mars which he named 'canali'. The canals, as they are popularly known, were studied in detail by Lowell at Flagstaff between 1895 and 1916, and were thought by him to be artificial waterways. This explanation is now discounted, and it seems that the 'canals' are not so narrow or so regular as Lowell believed; they are regarded as natural features (see **Mars**).

CANCER, TROPIC OF. See **Tropic.**

CAPRICORN, TROPIC OF. See **Tropic.**

CARBON. A non-metallic element of atomic weight 12, melting point about 3,500° C. and boiling point 4,200° C. It occurs naturally in three forms, as diamond, graphite or coal. It is the chief constituent of all forms of living or organic tissue. The carbon atoms can link themselves in long chains and rings to form the highly complicated molecules that are the basis of all living matter. No other atoms except those of silicon possess this property to a comparable degree, and it is reasonable to suppose that carbon is the prerequisite of **life.**

CARBON CYCLE. A nuclear reaction in which the carbon atom promotes the creation of helium from hydrogen. This process is accompanied by a vast release of radiation, and is, together with the proton-proton reaction, the main source of **stellar energy,** where both processes are described.

CARBON DIOXIDE, CO_2, is a colourless gas which forms 0.03% of normal air. It is produced when carbon is burnt in the presence of oxygen; hence animals, in whose bodies this reaction goes on continuously, inhale oxygen and exhale it again as carbon dioxide. The reverse is true of green plants.

In an enclosed, inhabited chamber such as a submarine or space ship, the carbon dioxide content of the air must be carefully controlled. The act of breathing is stimulated by the presence of CO_2, not by the lack of oxygen. A man breathing pure nitrogen, for example, will notice nothing wrong and will pass out, blue in the face and half suffocated, without a moment's discomfort. On the other hand he will pant violently if the CO_2 content of the air is doubled (perhaps from his own exhalation in a closed, small space) even if there is plenty of oxygen. The use of green algae has been suggested to remove the excess carbon dioxide and turn it back into oxygen, but is too cumbersome. It is far more likely that a space ship would employ nuclear methods similar to those that purify the air in the atomic submarines.

Large quantities of CO_2 have been detected in the upper atmosphere of Venus, and smaller amounts on Mars. It would be quite wrong to draw any conclusions from this either for or against the existence of plant life on these planets. (See **Life.**)

CARBON STARS. A fairly rare class of stars of spectral types R, N or S, unusually rich in carbon which exists free in their atmospheres.

CASSEGRAIN TELESCOPE. A reflecting telescope in which the light is reflected from the main mirror on to a secondary mirror and thence back through a hole in the centre of the main mirror into the eyepiece. See **Telescope.**

CASSINI DIVISION. The main division in Saturn's ring system, separating Ring A from Ring B. It has a width of 2,500 miles, and can be seen with a small telescope when the rings are well displayed. It is caused, like the other divisions, by the perturbing influence of Saturn's satellites, especially Mimas. See **Saturn.**

CASTOR. A multiple star with three visual components; the two brighter ones are themselves spectroscopic binaries, and the faintest is an eclipsing binary, making a total of six observable components. (See **Binary Star.**)

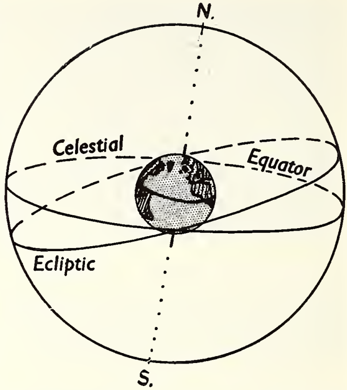
Castor and a nearby star called *Pollux* are together known as The Twins. They are not a perfect pair, as Pollux is almost 0.4 magnitudes brighter than Castor.

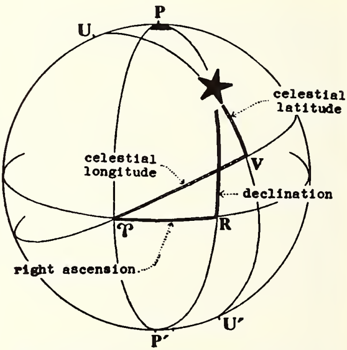
CELESTIAL EQUATOR (or *Equinoctial*) is the **Great Circle** in which the plane of the Earth's equator cuts the **Celestial Sphere.**

CELESTIAL SPHERE. To the naked eye the clear night sky appears domed like part of the inside of a gigantic sphere, and it is convenient to describe the direction in which a star is seen by stating the place it seems to occupy on this imaginary dome, the *celestial sphere*. This sphere is considered to be concentric with the Earth. The points on it which appear to be stationary during its daily revolution are the celestial north and south poles, and are the points in which the Earth's axis produced would cut the celestial sphere.

The plane of the Earth's equator cuts the celestial sphere in the *celestial equator*, and the plane in which the Earth's orbit round the Sun lies cuts it in the *ecliptic*. When we look at the Sun we are looking along this plane, and the Sun therefore always appears to occupy a point on the ecliptic, and to move along it.

The celestial equator and ecliptic cut each other in two points. The one through which the Sun passes about the 21st of March is called the *First Point of Aries*, or *Vernal Equinox*, and is often denoted by the sign γ representing the horns of Aries, the ram. The point is named after the near-by constellation Aries, in which it used to lie when early astronomers determined its position, but it has moved gradually away from that





THE CELESTIAL SPHERE: *P* and *P′* are the north and south celestial poles, *U* and *U′* the poles of the ecliptic. Right Ascension is measured eastward along the celestial equator from the intersection of the equator with the ecliptic, i.e. from the First Point of Aries.

(*Admiralty Manual of Navigation*)

constellation, owing to the **Precession of the Equinoxes.** Opposite to it on the celestial sphere is the *First Point of Libra*, or *Autumnal Equinox*, symbolized by the scales, ♎.

Just as on the Earth the position of a place is often given in terms of its latitude and longitude, so the position of a star on the celestial sphere is stated in terms of its *Declination* and *Right Ascension.* Instead of the Meridian of Greenwich, we draw an imaginary celestial meridian through the celestial pole and the First Point of Aries. The Right Ascension of a star is then the angle between this meridian and the meridian through the star. This corresponds to longitude on the Earth.

The declination of a star is the angle as seen from the centre of the celestial sphere between the star and the point on the celestial equator nearest to it; this corresponds to latitude on the Earth.

(Declination and Right Ascension must not be confused with *Celestial Latitude* and *Longitude*, which are similar in principle but are seldom used. The difference is made clear by the diagram.)

If a line is drawn from a star to the centre of the celestial sphere, which is also the centre of the Earth, this line will cut the Earth's surface in a particular point. This point is then at that moment the *Geographical Position* of the star, and to an observer at that place the star will appear directly overhead, i.e. at his *zenith.* This concept is fundamental to marine navigation.

Globes and a variety of map projections are used to represent the surface of the Earth. The same principles may be used to prepare **star globes** or star charts and atlases, but it is necessary to remember one important difference; places close to each other on a terrestrial map will in fact be close, but stars may appear to be almost next to each other in the sky (and therefore on a star chart) and yet be more removed from each other than others that seem further apart, i.e. which have a larger angular separation, as one star may be very far *beyond* its apparent neighbour. A star chart therefore gives no information about the true distances between celestial bodies. (M.T.B.)

CENTAUR. A U.S. rocket project for landing instruments on the Moon or sending probes to Mars and Venus.

CENTRE OF GRAVITY. The centre of gravity of any body is the point through which its entire mass may be held to act for most purposes.

Every body with clearly defined limits has such a centre of gravity, whether it be a solid, irregularly-shaped lump of matter or a vast sphere of gas like the majority of stars. The centre of gravity of a sphere is at its centre; that of a uniform rod is in the middle of the rod, half-way along its length; but sometimes it lies outside the body itself, as for instance in the case of a horseshoe, whose centre of gravity is in the middle of the space within the curve of the shoe.

When celestial bodies revolve about each other as they do in binary and planetary systems, they revolve strictly speaking about their common centre of gravity. The common centre of gravity of any two bodies always lies on the straight line joining their separate centres of gravity, and divides that line in the inverse ratio of their masses, so that it is always nearer the heavier body.

CEPHEID VARIABLE. A **giant star** which undergoes periodic changes in luminosity and size. The longer the period, the greater the absolute magnitude of this type of star, and since both the length of the period and the apparent magnitude are readily observable, the distance of a Cepheid variable can always be found. (See **Variable Stars** and **Magnitude.**)

CERENKOV DETECTOR. A detector of fast-moving sub-atomic particles which makes use of the *Cerenkov effect.* This effect is produced when a particle enters a substance such as glass at a velocity greater than that of light in the glass. (The theory of **relativity** shows that no object can travel faster than light in free space.) A 'shock wave' is produced, the particle being rapidly slowed down with the emission of light along the surface of a cone. The angle of the cone depends upon the velocity of the particle in the same way as the angle of a boat's wake depends on the boat's velocity through the water. The Cerenkov detector is constructed to receive only light emitted by this effect, and by positioning the detector to receive light from a Cerenkov cone of particular angle only particles within a given velocity range are detected.

CERES. The largest of the minor planets or **asteroids**, though not the brightest, and the first to be discovered (by Piazzi, in 1801). It proved to have the distance required by **Bode's Law** for the 'missing' planet. It has an estimated diameter of 485 miles, and a sidereal period of 4.6 years. At opposition it can attain magnitude 7.4.

o-**CETIDS.** See **Daytime Showers.**

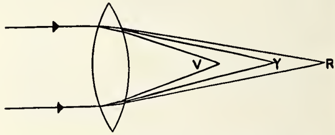
CHARACTERISTIC VELOCITY. The sum of all the velocities that have to be attained, or overcome for purposes of braking, by a rocket intended for a particular journey.

The following example, worked out for a journey from the Earth to the Moon and back, will illustrate the concept. The rocket would first have to reach a speed somewhat greater than the **escape velocity** for the Earth. It would then require no more fuel until it had to brake its fall on to the Moon, and in the absence of an atmosphere this could only be done by firing its rocket motors in the direction opposite to the line of fall. Where there is no friction, exactly as much fuel is needed for deceleration as for a corresponding **acceleration.** The Moon's escape velocity is 2.34 km/sec, and fuel to develop at least this speed in a forward and backward direction will be needed, backward to cancel the speed of fall, and forward for the subsequent take-off. Allowing for **gravitational loss**, and assuming that the landing on the return to Earth can be effected without power by following a path of **braking ellipses**, the characteristic velocity may be calculated from this addition:

Escape from Earth	12.5
Landing on Moon	3.0
Take-off from Moon	3.0
Navigational corrections . .	0.5
Characteristic velocity . . .	19.0 km/sec.

Neglecting slight differences in gravitational loss, this means that the fuel needed for such a journey, if fired all in one burst, would have to be enough to develop this speed. In other words, the characteristic velocity indicates how much fuel (or, more correctly, propellent) is required.

CHROMATIC ABERRATION. A defect inherent in optical **lenses**, due to the fact that they bend rays of light of different colours unequally. Violet light is refracted most, and red light least. Though the difference is slight, it does mean that an uncorrected lens will not bring all the colours of an image into focus in the same place, so that the image will be blurred. The coloured fringes seen near the edge of the field of view of an ordinary magnifying glass are an example of chromatic aberration.



A simple lens bends light of different colours unequally. The three foci shown are those of violet, yellow and red light.

The remedy is to use compound lenses containing three or even as many as six components all made of different glasses or other optical materials, such as quartz. Some components are concave and others convex lenses, and they are so arranged that, through partial cancellation of errors, the whole system brings all colours to the same focus, or at least all those colours to which the eye (or the camera) is most sensitive.

What is a nuisance in lenses is fundamental to the action of a **prism** in producing a spectrum, and without chromatic aberration spectroscopy would lack its chief tool.

CHROMOSPHERE (literally 'sphere of colour') is one of the inner layers of the Sun's atmosphere. Its name arises from the pink colour of its light, which is very evident during a total eclipse. See **Sun.**

CHRONOGRAPH. A clock with a mechanism that provides a written record of time on a moving strip of paper. A pen traces a continuous line and is activated every second by an electromagnet to draw a slight nick in the line. An observer who wants to record the exact time of an observation taps an electrical

For caption please see following page.

THE GREAT ORION NEBULA. This colour photograph shows the nebula as it would appear to us if the pupils of our eyes were the size of cartwheels. This plate should be compared with that on p. 196, which reveals finer detail in the central portion. The outlying parts of this vast cloud of gas extend over most of the Orion constellation, which is illustrated on p. 79. (*Mount Wilson-Palomar Observatories.*)

OVERLEAF: View from a hypothetical planet of the double star *Zeta Auriagae*, a faint member of the constellation *Auriga*, the Charioteer. The planet is assumed to be 400 million miles from the smaller of the pair of stars, which is here on the inner part of its orbit with relation to the planet. The visual angle is 35 degrees.

This binary consists of an enormous, cool supergiant 245 times the size of our Sun, and a very hot blue star $3\frac{1}{2}$ times as large as the Sun but a hundred times as bright. When passing behind its red companion, the blue star can be seen for some time before it is finally eclipsed by the supergiant's immense atmosphere. The two stars cast two-toned shadows on the surface of the planet.

key which will cause a similar nick to be made by a second stylus on a parallel line. A comparison of the two traces will then give the time with a minimum of personal error.

CIRCLE. The path described by a point which moves in a plane, maintaining a fixed distance (the *radius*) from a given point (the *centre*). It is a **conic section** of zero eccentricity.

CIRCULAR VELOCITY. The velocity with which a satellite must move to describe a circular orbit about its primary. See **Orbit.**

CLOCK. See **Time Measurement.**

CLOCK STARS. A number of bright stars whose **right ascension** is accurately known from observations made over long periods, used in **time measurement.**

CLOUD CHAMBER. See **Wilson Cloud Chamber.**

CLUSTER. See under **Galactic Cluster, Globular Cluster.**

CLUSTERS OF GALAXIES. These are aggregations of entire galaxies, and are not to be confused with galactic clusters, which occur in and are part of our own galaxy and consist of stars. Clusters of Galaxies are discussed under **Extragalactic Nebulae.**

COAL SACK. An area of the Milky Way in the southern sky where stars are greatly obscured by a cloud of dark material (see **Galactic Nebula**). It appears devoid of stars to the naked eye, although a telescope shows them to be shining dimly through it.

COLLIMATOR. An optical arrangement for collecting light from a source into a parallel beam. It is often simply a converging **lens,** with the source at its focus. It forms an important part of spectroscopes. (See **Spectroscopy.**)

COLOUR INDEX. The human eye differs from the photographic emulsion in its sensitivity to light. It is in fact blind to many parts of the **electro-magnetic spectrum** that are registered by the camera. Visual **magnitude** is therefore not equal to photographic magnitude:

Colour index = photogr. magn. — visual magn.

The region of the spectrum in which the radiation of a star is at a maximum depends largely on its temperature, and will affect the colour index according to whether it is nearer the region of maximum sensitivity of the eye or the photographic plate. Colour index is therefore an approximate guide to the temperature of a star, especially between 3,000° and 15,000° C.

COLOUR-MAGNITUDE DIAGRAM is a variation of the **Hertzsprung-Russell diagram,** with **colour index** substituted for spectral type.

COMA. The vaguely defined area of light at the head of a **comet,** in which the nucleus is embedded.

The word is also used in astronomy for the blurred haze sometimes surrounding the images of stars in the outer parts of a photograph, due to optical imperfections.

COMET. A nebulous body which revolves about the Sun in an elongated ellipse. The name is derived from a fanciful resemblance of the tail to a tress of hair streaming in the wind (Greek *kometes,* long-haired), and this may have led to the erroneous opinion that comets rush across the sky (like meteors) with their tails streaming behind them. The fact that the tails of comets always point away from the Sun seems to have been first stated by Peter Apian in 1531, while Tycho Brahe showed that comets are father away than the Moon. Since their motion is the same as that of the planets, it follows that they have similar apparent movements, remaining in sight for long periods, while moving slowly among the stars. The fainter comets may only be seen for a few days, depending on the circumstances of their discovery and the direction of their motion, whether towards or away from the Sun.

Comets are always brightest when near the Sun, and are then seen in the western sky at sunset, or in the East at sunrise, their tails pointing upwards from the horizon. As a comet approaches the Sun, its tail grows longer and larger, and the whole object

brightens. As it swings round the Sun, the tail, still streaming away from the Sun, swings round also, so that it *precedes* the comet in its outward journey. Not all comets are seen like this. Most of them are disappointingly small nebulous objects, vague in form, and without any kind of central condensation. This may develop later, taking the form of a stellar *nucleus*, bright and star-like in appearance. The nebulosity surrounding the nucleus is called the *coma*, the two together forming the *head* of the comet. At a later stage, generally at a distance of about 1½ units from the Sun, the coma becomes unsymmetrical, showing that a tail is beginning to develop; in some cases a definite tail is seen, and may, in exceptional cases, reach imposing proportions (see e.g. **Halley's Comet**). The brightening of the whole object as it approaches the Sun is accompanied by changes in the structure; *jets* (or *beards*) of luminosity are seen, extending in a direction *towards* the Sun, and these are often swept back to form envelopes which are clearly parabolic in shape and which, like the coma, merge imperceptibly into the tail. The coma itself, rather surprisingly, contracts as the comet nears the Sun, and expands again after perihelion passage. Changes in the structure of the tail are frequent, and a comet may develop many separate and clearly distinguished tails.

In the past, discoveries of comets were made entirely by chance, and before the use of the telescope only the brightest comets were seen. With optical aid, it became possible to search for comets, and many discoveries were made by comet-hunters such as Pons and Messier. There is still room for this class of work, for it is still true today that most comets are discovered by accident. Only in the case of the periodic comets, for which predicted places are published in advance, is any systematic search made with large instruments, and this only in a very few centres. Few observatories can afford to devote the time of their instruments to routine work on comets, and this branch of astronomy is greatly neglected, especially in the southern hemisphere. When large instruments can be employed, they are capable of detecting comets at a much fainter stage than was ever possible in the past, particularly in cases where photography is used with telescopes of short focal length: no less than ten comets have been found within five years in the course of the sky survey undertaken with the 48-inch **Schmidt camera** of the Mt. Palomar observatory. Similarly, the Czechoslovak astronomers have made something of a record with their discoveries of comets in the course of their routine sweeps of the sky while studying meteors. The number of comets found varies from year to year:

Year	*New*	*Periodic*
1951	6	6
1952	5	1
1953	4	5
1954	6	5
1955	5	3

Since in any one year some of the previous year's discoveries will still be under observation, the number actually visible during the year is larger than shown above; in 1951, no less than 22 comets were under observation.

TAILS. The tail of a comet is always its most impressive feature, and even when quite small may show remarkable changes of form. The tails of the great comets may extend half way across the sky, exciting alarm and superstitious fear. Yet the tail is extremely tenuous, being quite transparent, and having no obvious effect on the light of the stars seen through it.

Such a tail may be 50 to 150 million miles in length, and perhaps 5 to 10 million miles wide at the end farthest from the Sun, yet in spite of this great size, it can possess very little mass. There is often evidence of curvature in a long tail, and this effect is greatly enhanced by perspective, the curvature being exaggerated when the observer sees the tail foreshortened.

It is generally agreed that the nucleus of a comet consists of solid blocks or particles of a similar constitution to meteorites, and that these are surrounded by the gases which are expelled from them by the heat of the Sun. The tail consists of a mixture of these gases with fine dust, and these particles are repelled by the solar **radiation pressure.** The existence of this effect has been demonstrated by laboratory experiments, and the pressure is known to be proportional to the cross-sectional area of the particle. The gravitational attraction of the Sun, however, is proportional to the mass of the particle, and therefore to its volume, and acts in the opposite direction to the radiation pressure. There is thus a definite size of particle for which the two forces will be equal, and this can be shown to be of the order of a micron (= 0.001 mm). Schwarzschild has shown that the radiation pressure is a maximum for particles of the order of one third of the wavelength of the light which falls on them. Very little repulsive force can be experienced by gas particles, which are too small, but it is possible for the gas to absorb radiation at particular wavelengths (selective absorption) and this will have a similar effect. Although this theory is satisfactory in its broadest generalizations, it gives no explanation for the remarkable changes that are seen to take place in the tails. In the case of Morehouse's comet of 1908, the repulsive forces were found to be 800 times gravity; in other cases multiple tails have been seen, some of which appear at unusual angles from the nucleus.

The most fruitful theory of the structure of comets is that of Whipple, who considers that comets are made of a conglomerate of spongy meteoric material with 'ices' consisting of gases such as methane, water, ammonia and carbon dioxide. These will all remain solid under the conditions of interplanetary space, but as the comet approaches the Sun solar radiation will cause some of the gases to evaporate, leaving an outer matrix of

COMET MOREHOUSE on November 19, 1908, showing the formation of multiple tails.

(Royal Greenwich Observatory)

poorly conducting material. Mathematical treatment shows that under these conditions the heat of the Sun is transferred across the thin meteoric layers very slowly, and mainly by radiation. If the head of the comet is rotating, there is a considerable time lag before the heat reaches more of the solidified gases, so that the gases will be emitted at a different angle from that of the solar radiation. There will therefore arise a small force directed at an angle to the Sun's gravitational attraction, and this may increase or decrease the velocity of the comet, according to the direction of rotation of the nucleus. In this way Whipple has been able to explain the acceleration in the motion of Comet Encke and the deceleration of Comets d'Arrest and Wolf (1); it has also proved possible to use this theory to explain the outbursts of light in certain comets, as well as many features of the disruption of comets and the formation of **meteors** and the **zodiacal light.**

COMET FINSLER, 1937. During the five-hour exposure, the comet moved relative to the background stars. As the camera was kept guided on the comet, the stars appear as trails on the photograph. (*Norman Lockyer Observatory*)

SPECTRA OF COMETS. The **spectrum** of a comet consists of a number of bands superimposed on a faint continuous spectrum. In the brighter comets the continuous background shows the **Fraunhofer lines** of the solar spectrum, so that it is clearly due to reflected sunlight. The bands have been identified with the molecules C_2, CH, CN, OH, NH, NH_2 and CH_2 and the ions N_2^+, CO^+, CH^+ and OH^+, all of which are chemically unstable and must owe their existence in the coma and tails of comets to the extremely low density and freedom from collisions. These spectra involve the ground state of the molecules, and are due to fluorescence excited by the Sun. The gases which give rise to these spectra must be identical with those found occluded in meteorites, viz., carbon monoxide CO, carbon dioxide CO_2, methane CH_4, hydrogen H_2 and nitrogen N_2. Comets must presumably contain ammonia NH_3, and water H_2O as well, but apart from this, there is a very close connection between the two classes of body, which is readily explained on Whipple's hypothesis.

LUMINOSITY. It is customary in comet work to quote the brightness of a comet in terms of ordinary stellar magnitudes, but the results are not entirely satisfactory. While it may be possible to estimate the brightness of the stellar nucleus, an estimate of the total magnitude is much more difficult. Attempts have been made to standardize procedure by comparing the total light of the comet with that of a standard star out of focus; but such estimates leave much to the judgment of the observer, and the results are frequently discordant. In spite of this, the measurements are of importance in revealing the remarkable changes that take place in the luminosity of certain comets.

The brightness of a planet or comet must depend on the intensity of illumination it receives from the Sun, and on its distance from the Earth, being proportional to the inverse square of each of these quantities (see **Light**). But few comets follow such a simple law, and although the arbitrary introduction of inverse fourth and even sixth powers has served to predict the brightness of future returns of periodic comets, it is rare for the values to be followed with any accuracy. The rapid variations in the form and brightness of the tail of Comet Morehouse (1908) led to the suggestion that there was some connection between these changes and the presence of sunspots on the Sun, and similar ideas were put forward in the case of certain other comets.

Unfortunately, the period of visibility of a comet is generally too short to allow of an extensive series of measurements of this kind. The only comet for which numerous observations have been published is Schwassmann-Wachmann (1), which is almost continuously visible. Normally a faint object, it undergoes remarkable outbursts, such as that of January 1946, when it brightened from magnitude 16 to 10.2 on January 25 and to 9.4 on January 26; a week later it had dropped back again to magnitude 15. There was at the time a giant sunspot, turned towards the comet, and further outbreaks of the same nature seem to have a definite correlation with solar activity. It has been pointed out, however, that the amount of energy reaching the comet from solar outbursts is too small to do more than initiate some change within the comet itself. These great outbursts must apparently have an origin within the nucleus, and

Whipple's theory of the structure would seem to be capable of supplying an explanation.

MASSES OF COMETS. Although the nucleus of a comet may be quite large – diameters up to several thousands of kilometres have been reported – the mass of a comet is always small, in comparison with that of the planets. It may be estimated by the absence of perturbative effects, as in the case of Lexell's comet of 1770, which passed within 1½ million miles of the Earth without causing any change in the length of the year. The same comet in 1779 passed so close to Jupiter that it crossed the orbits of the inner satellites, yet although the orbit of the comet itself was completely altered (it has never since been seen) the satellites were in no way affected. It is concluded that the mass of the comet must have been less than one millionth of the mass of the Earth. But even this is by no means negligible, and a collision with a mass of this order, moving with planetary speed, would be catastrophic.

Because of their small mass and large size, the mean density of comets is extremely low, about half an ounce per cubic mile. (A cubic mile of air at sea-level weighs 5 million tons.) It seems likely that the nucleus consists of separate blocks of material, or of small particles widely separated. The comet of 1862 and Halley's Comet of 1910 both passed between the Earth and the Sun, but nothing was seen of them as they moved across the face of the Sun.

THE AREND-ROLAND COMET, 1956 *h*. Discovered in 1956, this exceptional comet was the brightest to be seen in northern latitudes since the Daylight Comet of 1910. An unusual feature was the long spike projecting from the head towards the Sun. The picture shows just over two-thirds of the 7,000,000-mile length of the comet.

(*University of Michigan Observatory*)

NOMENCLATURE. Comets are usually named after their discoverers, as many as three names being appended in some cases. For some important periodic comets, the names are those of astronomers who have worked on the perturbations of the orbits; examples are Comets Halley, Encke and Crommelin. At the time of its discovery the comet is designated by the year of discovery, followed by a Roman letter. When the orbits have been determined this numbering is changed to give the order of perihelion passage, the year being followed by Roman numerals. Thus comet 1951*h* Comas Solá became 1952 VII, while 1951*l* Schaumasse is known as 1952 III.

ORBITS. Since a comet moves under the gravitational force of the Sun, its orbit must be a **conic section**. Such an orbit can be calculated from three suitably spaced observations, but since only a small part of the path is covered in a short time-interval, it is convenient to assume that the path is a parabola. This simplifies the calculation, and is often sufficiently accurate, since the arc over which the comet is observed is but a small fraction of the whole orbit, and its curvature is almost indistinguishable from that of a parabola. When more observations have been made, it is possible to compute a more accurate orbit, and under modern conditions few parabolic orbits are published. This increase in accuracy enables us to be certain that all comets are members of the

solar system, moving in elliptical orbits, which may, however, be so large and eccentric as to be almost parabolic in form, so that **perturbations** may be sufficient to convert them into hyperbolas, in which cases the comets would not return.

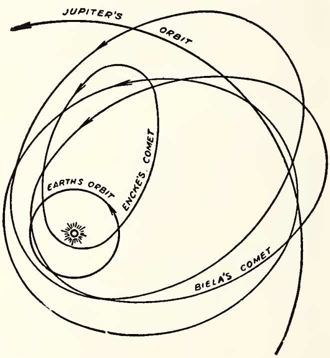
Present catalogues of cometary orbits give particulars of 761 orbits, representing 549 individual comets, of which 205 travelled in ellipses, 291 in parabolic and 53 in hyperbolic orbits. The number of periodic comets now known makes it imperative to make a continuous review of their perturbations, in order to make predictions for future returns. The prediction takes the form of an **ephemeris**, giving the position of the comet at stated intervals, and is based on the calculation of perturbations over at least one revolution. This is of little avail if the original orbit is not a good one; hence the work consists of (a) using all available observations to correct the orbit, (b) computing perturbations, and (c) computing the ephemeris. The perturbations in some cases are severe, and entail much labour in their computation; in less extreme cases, approximate methods are sufficient, and these are amenable to treatment by electronic computing machines.

STATISTICS. In any study of the orbits listed in the comet catalogues, it is at once obvious that we are dealing with a very restricted selection of orbits. For instance, the values of perihelion distance are always small, and mainly in the neighbourhood of one **astronomical unit**; this is a natural outcome of the fact that comets are visible to us only when they come near to the Earth. The extreme values for perihelion distance are 5.523 for Comet 1925 I, and 0.00549 for Comet 1880 I.

The orbit of a periodic comet is an ellipse with the Sun in one of its foci. For a given perihelion distance, there must therefore be a definite relationship between the length of the major axis of the ellipse and its eccentricity (see **Conic Section**). It is, in fact, one of the noticeable features of a comet catalogue that the comets of longest period (i.e. those with the largest values for the major axis) have also the largest eccentricities. All the comets with periods of more than 200 years have eccentricities greater than 0.96. The comets of shorter period have a much wider range of eccentricity, two having e less than 0.15, while the others lie between 0.3 and 0.993.

The inclinations of cometary orbits to the ecliptic are often stated to be distributed over the whole range from 0° to 180°, and while this is true, the distribution is far from being a random one. There is a definite tendency for the orbits to crowd towards the ecliptic, so that small inclinations near 0° and 180° predominate. This is particularly true of the short period comets, all of which, with only two exceptions, travel in direct orbits with small inclinations. There is some evidence of the effect of Jupiter on these short period comets, since their perihelia show a tendency to crowd towards the position of Jupiter's perihelion. Many of these comets have aphelia which lie near the orbit of Jupiter, and the effect is due to perturbations.

COMET GROUPS. It is always possible to find similarities between the elements of a newly discovered comet and those of an older one. In some cases the resemblances are so striking as to lead to the idea of comet groups, a very large number of which are known. By far the most interesting of these groups is that which included the great comets of 1843 and 1882.



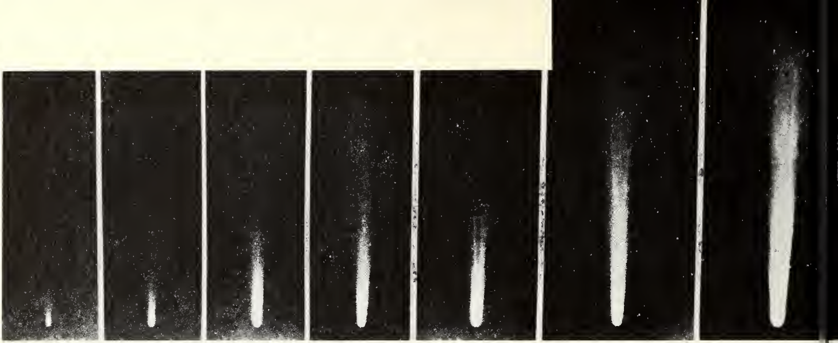
JUPITER'S FAMILY OF COMETS. All the above orbits have been strongly influenced by the great planet, and their aphelia now lie close to its course. Encke's orbit is also the smallest known, and the comet returns every 3.3 years.

All of these comets had highly eccentric orbits with very small perihelion distance – they are often referred to as the sun-grazing comets – and very similar inclinations. Five out of the six have their aphelion in practically the same direction from the Sun. Yet it is impossible that any two of them should be appearances of the same comet. Hence it appears that this group of bodies travels along what is, in effect, the same path, and there is here an analogy with the behaviour of comets and their associated meteor streams. It is impossible for two comets to continue indefinitely in the same path, since perturbations alone will tend to separate them, but the existence of these groups lends support to the view that the individual members arose from the disruption of some giant comet in the remote past.

COMET BROOKS photographed during its return in 1911. Star trails can be seen through its tail and even through part of the head.

SHORT PERIOD COMETS. Those comets which have been seen at more than one return to the Sun are listed in the Table of Comets, in order of period. It was the practice in the past to relate such comets to one or other of the major planets. Thus there is a large group of comets with periods of about 6 years, having aphelia which lie near Jupiter's orbit, at a distance of about 5 units; similar groups have aphelion distances comparable with the distances of Saturn, Uranus or Neptune. This idea of comet families, however, must be regarded as fortuitous, since in most cases the inclinations of the orbits will prevent the comets from passing near enough to the planet to come under its gravitational influence. Thus Halley's comet, which is frequently referred to as belonging to the Neptune family, has the smallest inclination of any comet associated with this planet; yet it actually passes at a distance of 8 units from the orbit of Neptune, although approaching much more closely to Jupiter. In general it may be said that Jupiter is almost entirely responsible for any of these arrangements.

The shape and size of the short period cometary orbits is clearly a result of prolonged perturbations by Jupiter, and the statistics of these orbits show several interesting correlations with that of Jupiter. Since all of the 6-year comets travel in direct orbits, they will be moving slowly at aphelion in the same direction as Jupiter, and may come under the influence of that planet for lengthy periods. In extreme cases there may be a close approach, when the orbit of the comet will be greatly altered. As an example, Brooks (2) 1889 V, had its period changed from 29 years to 7 years by a close approach to Jupiter in 1886; at another close approach in 1921 the elements of the orbit were again altered: the longitude of perihelion has changed very little, but the whole orbit has altered its inclination about the line of **nodes** by about 12°. A more common case is that in which a comet suffers perturbations by Jupiter at each alternate revolution. Comet Pons-Winnecke shows this behaviour clearly, since its period is about half that of Jupiter. Its orbit is steadily becoming more circular and inclining at an increasing angle to the ecliptic. This comet gave rise to a meteor shower in 1916, when the distance between the comet's orbit and that of the Earth was a minimum. Another comet which has given rise to a great shower of meteors during the present century is Comet Giacobini-Zinner, first discovered by Giacobini in 1900, and recovered by Zinner in 1913 (see **Meteor**).



Apr. 26 27 30 May 2 3 4 6

HALLEY'S COMET IN 1910. The alterations in the appearance of the comet between successive photographs are due to changes in distance and foreshortening as well as to actual changes of its shape.

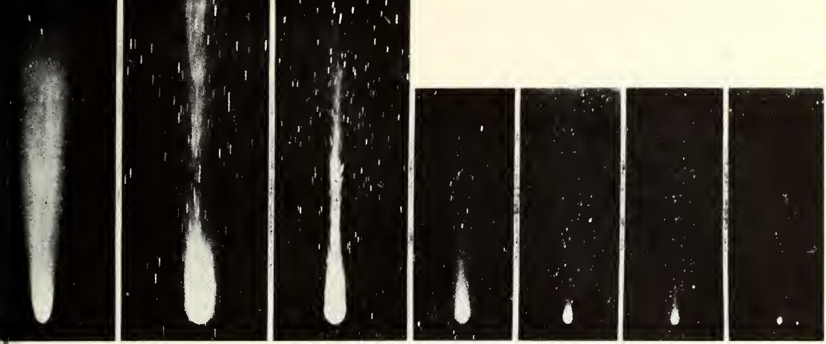
(*Mount Wilson – Palomar*)

Perhaps the most interesting of all the short period comets is **Halley's Comet.** Soon after Newton's work on the laws of gravitation, Halley collected observations of 24 comets, and deduced the elements of their orbits. Struck by the similarity between the orbits of the comets of 1531, 1607 and 1682, he concluded that they were three appearances of the same comet, and rightly attributed the difference in the intervals to perturbations by Jupiter. Although no certain method of computing the perturbations was then known, Halley ventured to predict the return of the comet in 1758. Its return on Christmas Day of that year, sixteen years after Halley's death, was the first of many such applications of Newton's Laws. In the following century many new methods for computing perturbations were invented, but most of these are too laborious for use in the case of a comet of such a lengthy period. In 1910 Cowell and Crommelin used a new method to predict the 1910 return, and this was so accurate that it won the *Astronomische Gesellschaft* prize for a successful prediction of this apparition. Subsequently these two computers carried the investigation of Halley's comet back to 240 B.C., and were able to check their figures against many ancient records. The most interesting of these is the appearance of Halley's comet in 1066, an event which is recorded on the Bayeux tapestry. The next return of this comet will take place in 1986.

It is interesting to note that, although Halley's comet travels in a retrograde orbit, perturbations are sufficiently great to cause the period to vary from 76.0 to 79.6 years. For more than three-quarters of this time the comet is beyond the orbit of Neptune, its speed at aphelion being only 0.91 km/sec as compared with its perihelion speed of 54.56 km/sec. This is characteristic of all comets, but is most noticeable in the case of the more eccentric orbits, since the perihelion and aphelion speeds are in the ratio of $1 + e$ to $1 - e$.

Encke's Comet, which has the shortest period known, furnished the second instance of the return of a comet. Encke was a pupil of Gauss, who had devised a new method for computing elliptical orbits, and in 1818 Encke computed the orbit of a new comet discovered by Pons. Not only did it prove to have the short period of 3.3 years, but it was also found to be identical with Comets Méchain 1786, Caroline Herschel 1795 and Pons 1805. Encke rounded off this notable piece of work by predicting the return of the comet in 1822, when it was duly recovered. This comet appears to be associated with the **Taurid** meteor shower.

Although most comets travel in eccentric orbits, there are two exceptions whose paths



15 23 28 June 3 6 9 11

are certainly no more eccentric than those of the minor planets. Comet Schwassmann-Wachmann (1) has the smallest eccentricity of all comets (0.136) and its orbit lies wholly between those of Jupiter and Saturn. It has been seen each year since its discovery in 1925, and its remarkable outbursts of light have already been referred to above. Comet Oterma is also visible at each opposition, and has an orbit that lies in the minor planet belt between Mars and Jupiter. Its orbit, which has an eccentricity of 0.144, closely resembles that of an asteroid of the *Hilda* group.

LONG PERIOD COMETS are known with times of revolution up to many thousands of years. The larger values must be regarded with caution; thus the period of 3,910,000 years quoted for Comet 1910 I merely means that the orbit was almost a parabola. The astronomer is more interested in the dimension a than in the period, but a is strongly correlated with e (see **Conic Section**). Such a large value of a therefore implies a large value of e, and the orbit may well be changed from an ellipse to a hyperbola by planetary perturbations. Nevertheless, long periods must be accepted for the majority of comets, and if this is so, their numbers must be very great. Thus Crommelin estimated that comets might have an average period of 40,000 years, and if 300 new comets are seen in each century there must clearly be at least 120,000 of them revolving about the Sun.

All of the hyperbolic orbits must belong to this group. In all such cases the eccentricity is only slightly greater than unity, and in every case where sufficiently accurate data are available, it has been proved that the hyperbolic nature of the path is due to planetary perturbations, the comet having previously revolved in an elongated ellipse, The facility with which such changes may take place is indicated by the fact that Halley's Comet, which has a speed of 54.56 km/sec at perihelion, would have its orbit converted into a hyperbola if this speed were increased to 55.1 km/sec. The changes necessary to alter a comet of really long period in this way would be very much less.

DISRUPTION OF COMETS. The actual disruption of a comet has been witnessed on various occasions, but there is no evidence to connect such an event with perturbations or any other external phenomenon. The sungrazing comets such as that of 1843 must have undergone severe heating and other disruptive effects, since they actually passed through the solar corona, yet their rapid passage round the Sun seems to have caused little change. In the case of the comet of 1882 the nucleus was seen to have broken into separate parts, which were referred to as a 'string of pearls'. The most interesting case of disruption is that of Biela's comet, which was discovered in 1826, and shown to be the same comet as those of 1772 and 1805. It was recovered in 1832 and again in 1846, but in this year the comet divided into two parts. The two comets travelled side by side and were seen again at the 1852 return, rather more widely

TABLE OF COMETS

COMET		No. of Appear-ances	*Period (Years)*	*Perihelion Dist. (in A.U.)*	*Eccen-tricity*	*Incli-nation*
1953 *f*	Encke	44	3.30	0.338	0.847	12°.4
1952 IV	Grigg-Skjellerup	8	4.90	0.856	0.704	17°.6
1954 *a*	Honda-Mrkos-Pajdus-áková	2	5.21	0.556	0.815	13°.2
1951 VIII	Tempel (2)	11	5.30	1.391	0.543	12°.4
1927 I	Neujmin (2)	2	5.43	1.338	0.567	10°.6
1879 I	Brorsen (1)	5	5.46	0.590	0.810	29°.4
1951 IV	Tuttle-Giacobini-Kresák	3	5.49	1.117	0.641	13°.8
1908 II	Tempel-Swift	4	5.68	1.153	0.638	5°.4
1894 IV	De Vico-Swift	3	5.86	1.392	0.572	3°.0
1879 III	Tempel (1)	3	5.98	1.771	0.463	9°.8
1951 VI	Pons-Winnecke	15	6.12	1.159	0.654	21°.7
1951 VII	Kopff	7	6.18	1.495	0.556	7°.2
1948 VIII	Forbes	3	6.42	1.545	0.553	4°.6
1955 *i*	Perrine-Mrkos	3	6.46	1.154	0.667	15°.9
1954 *g*	Schwassmann-Wachmann (2)	5	6.53	2.150	0.385	3°.7
1953 *d*	Reinmuth (2)	2	6.59	1.867	0.469	7°.1
1946 V	Giacobini-Zinner	6	6.59	0.996	0.717	30°.7
1852 III	Biela	6	6.62	0.861	0.756	12°.6
1950 V	Daniel	4	6.66	1.465	0.586	19°.7
1954 *j*	Wirtanen	2	6.69	1.625	0.542	13°.4
1950 II	d'Arrest	10	6.70	1.378	0.612	18°.1
1953 *i*	Finlay	6	6.81	1.049	0.708	3°.4
1906 III	Holmes	3	8.86	2.122	0.412	20°.8
1953 *b*	Brooks (2)	9	6.93	1.866	0.487	5°.6
1954 *b*	Borrelly	6	7.01	1.448	0.604	31°.1
1954 *e*	Faye	14	7.41	1.652	0.565	10°.6
1955 *d*	Whipple	4	7.42	2.450	0.356	10°.2
1955 *c*	Ashbrook-Jackson	2	7.51	2.324	0.394	12°.5
1950 IV	Reinmuth (1)	3	7.69	2.037	0.477	8°.4
1950 III	Oterma (3)	—	7.89	3.390	0.144	4°.0
1952 III	Schaumasse	5	8.17	1.194	0.706	12°.0
1950 VI	Wolf (1)	9	8.42	2.498	0.396	27°.3
1952 VII	Comas Solá	4	8.55	1.766	0.578	13°.5
1949 V	Väisälä (1)	2	10.52	1.752	0.635	11°.3
1951 V	Neujmin (3)	2	10.95	2.032	0.588	3°.8
1938 I	Gale	2	10.99	1.183	0.761	11°.7
1939 X	Tuttle	8	13.61	1.022	0.821	54°.7
1941 VI	Schwassmann-Wachmann (1)	2	16.15	5.523	0.136	9°.5
1948 XIII	Neujmin (1)	3	17.93	1.547	0.774	15°.0
1928 III	Crommelin	4	27.91	0.745	0.919	28°.9
1942 IX	Stephan-Oterma	2	38.96	1.596	0.861	17°.9
1913 VI	Westphal	2	61.73	1.254	0.920	40°.9
1919 III	Brorsen-Metcalf	2	69.06	0.485	0.971	19°.2
1956 *a*	Olbers	3	69.57	1.179	0.930	44°.6
1953 *c*	Pons-Brooks	3	70.88	0.774	0.955	74°.2
1910 II	Halley	29	76.03	0.587	0.967	162°.2
1939 VI	Herschel-Rigollet	2	156.00	0.748	0.974	64°.2
1907 II	Grigg-Mellish	2	164.30	0.923	0.969	109°.8

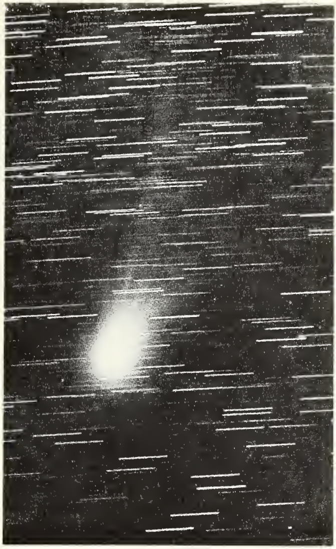
separated. They have not been seen since, but in 1872 there occurred a spectacular display of meteors from a **radiant** which was shown to have a position in agreement with the elements of the comet. A recent event of this kind occurred in connection with Comet 1955 *g* Honda which was seen at Lick to have twin nuclei 5″ apart.

ORIGIN OF COMETS. Among the many speculative ideas of the origin of comets, some form of disruption theory has always been preferred. A suggestion by Lagrange, that comets might originate from an explosion on a planet such as Jupiter, has also had some support. A mathematical analysis, however, shows that the distribution of the inclinations of cometary orbits cannot be accounted for in this way, but is best explained in terms of a capture theory, in which the planet Jupiter is considered to be responsible.

This analysis has been extended to give a comprehensive picture of the system of comets. It may be that new comets come from distances of the order of 50 to 150 thousand units, and that within this range there is a cloud of 10^{11} comets surrounding the Sun. Their total mass may amount to 1/10 to 1/100 of that of the Earth, and they are perturbed not only by the planets but also by the stars. The stellar perturbations carry the comets from the cloud to meet the Earth, and it is thus possible to explain both the preponderance of nearly parabolic orbits, and the random distribution of the orbital planes. This theory throws into prominence the necessity for further study of the 'new' comets, especially those of very long period, and of the investigation of their perturbations backwards into the remote past. This is a task well suited to modern electronic computing machines. (J.G.P.)

COMPUTING MACHINE. A machine that performs laborious calculations. Computing machines are becoming increasingly important in all branches of science, and in none more than in astronomy and upper atmosphere research. They can do nothing that a skilled human computer cannot do, given enough time, but they work incomparably faster.

There are three broad categories: analogue, digital and punched-card computers. An *analogue computer* makes use of models whose dimensions represent the quantities upon

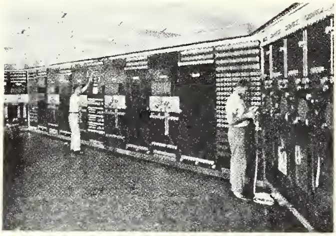


COMET PERRINE, 1902.
(*Royal Greenwich Observatory*)

which the operations such as addition, multiplication and integration are performed; it may be regarded as a highly elaborated slide-rule, with oddly shaped components. A *punched-card machine* is well adapted for statistical work. Information is entered on a card by making holes in it in certain positions, just as the holes clipped in a bus ticket can indicate where and when the passenger boarded the bus. Hundreds or thousands of such cards, all punched according to the same system for any given problem, are fed through the machine at speed. Electric contacts 'feel' the holes, and stack and count the cards accordingly. Some cards may actually contain instructions coded in terms of holes telling the machine how to deal with the cards.

By far the most interesting and flexible computers are the *electronic digital* ones. Here each number is represented by a sequence of electric pulses, usually in the *binary* scale.

 CONIC SECTIONS



Part of an electronic computing machine operated by the U.S. Navy. The man on the right is examining tape from the machine that punches out answers to problems.

Writing + for a pulse and o for a pause of definite length between pulses, the first few numbers can be signalled like this:

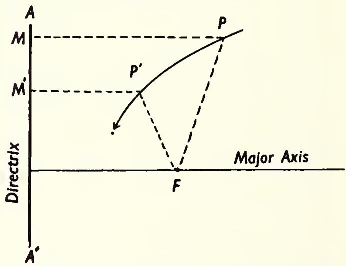
1 =	+	5 =	+ o +
2 =	+ o	6 =	+ + o
3 =	+ +	7 =	+ + +
4 =	+ o o	8 =	+ o o o, etc.

These patterns of sharp electrical 'kicks' and pauses are the form in which the machine handles all numbers; the most complex problems are reduced to perhaps thousands of simple additions and subtractions, each one of which requires no more than a very small fraction of a second. Results and data can be stored in the 'memory', where the pattern of pulses is recorded on magnetic tape, on fluorescent screens or as a pattern of vibration waves travelling through long tubes of liquid mercury. When a particular number is required again from the memory, the tape, the vibrations, or the screen together with a scanning device, can reform the pulse pattern. Final results are written by a form of teleprinter or perhaps plotted on a moving strip of paper like a graph, or transmitted at once to another mechanism such as a rocket in flight whose guidance depends on the results of the calculations.

An electronic machine can memorize, check its own work for mistakes, indicate its degree of accuracy, and it can even learn and gain from experience. But it cannot think. In the last resort, it can do nothing except follow the programme of additions and subtractions and other simple operations that has been prescribed for it by a mathematician, the *programmer*, for each particular kind of problem. If the programmer does not know how to tackle a task, the machine can do nothing for him.

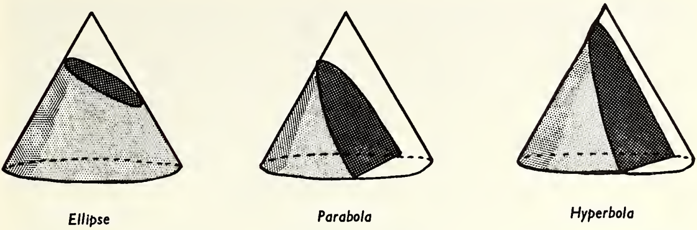
CONIC SECTIONS are curves which may all be obtained as the result of cutting a cone in various ways. If the cut is made parallel to the base of the cone, the shape of the resulting cross-section will be that of a *circle*; if the cut is somewhat inclined, it will be an *ellipse*; if the cut is made parallel to the slope of the side of the cone, it will be a *parabola*; and if the cut is inclined at a still greater angle, it will be a *hyperbola*. Finally, a cut through the very tip of the cone gives a *point*, and one along its edge, a straight *line*. The last two are extreme cases of a very small circle and of a very narrow parabola respectively.

The importance of the conic sections in astronomy is that any body that moves in an unperturbed **orbit** will follow a path that is in fact one of the conic sections. We can define and classify these curves according to their *eccentricity*, as follows:

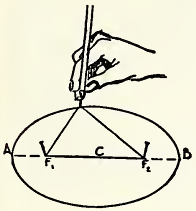


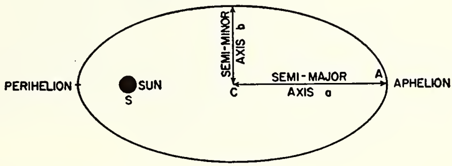
The curved line is part of a conic section. PF : PM = P′F : P′M for any two points on the curve. In the above example, this ratio is 3 : 4, i.e. less than 1, and the curve is therefore part of an ellipse.

Let there be any fixed straight line, *AA′* (usually called the *directrix*), and a fixed point *F*, not on the line itself. Let us now consider any other point on the same sheet of paper (i.e. in the same plane). Its distance from the fixed point *F* is *PF*, and its distance from the fixed line is *PM*, where *PM* is perpendicular to *AA′*. We call the ratio of



Above: the ellipse, parabola and hyperbola as oblique cross-sections of a cone. *Lower left:* how to draw an ellipse. A loop of cotton is placed over two pins stuck in the foci and is kept taut by the pencil point as the curve is drawn. *Lower right:* the ellipse as a planetary orbit.



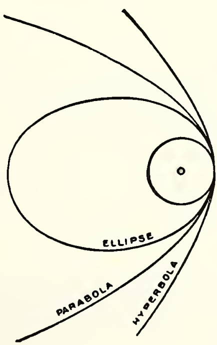


PF : *PM* the *eccentricity*; its precise value will depend on whatever position we have chosen for *P*. If this point *P* is now allowed to move, but in such a way that the ratio *PF* : *PM* remains constant, it will describe one of the conic sections. If the eccentricity $e = 1$, i.e. if *PF* always equals the distance of *P* from the straight line, the curve will be a parabola; for a smaller eccentricity, it will be an ellipse, a very elongated one if the eccentricity is almost 1, and an almost circular one if e is nearly zero. (If e is exactly zero, the ellipse becomes a circle; clearly e can only be zero if the directrix is infinitely far away.)

Thus by stating the eccentricity of an orbit, one states its exact shape, though not its size. The point *F* is called a focus and the Sun is always at a focus of the orbits of its planets and the comets.

Summing up:

$e > 1$	HYPERBOLA
$e = 1$	PARABOLA
$e < 1$	ELLIPSE
$e = 0$	CIRCLE



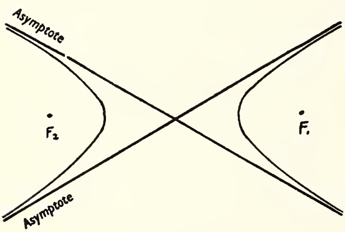
THE ELLIPSE. This is the shape of all closed, unperturbed orbits. *Perihelion* and *aphelion* are at opposite ends of the *major axis*.

THE PARABOLA. It is doubtful whether any celestial body ever moves in a truly parabolic orbit, since the slightest perturbation would make e a fraction greater or smaller than unity and so change the character of the orbit but the difference may be negligible for practical purposes. All projectiles and ballistic missiles move approximately in parabolas once the propelling force has ceased to act.

An important property of a parabolic surface is that it will bring parallel rays striking it to a focus, and will reflect rays from the focus into a parallel beam. Reflecting telescopes, car headlights, electric heaters and radar reflectors are some of the many cases in which this principle is applied.

THE HYPERBOLA. This curve has, strictly speaking, two *limbs*. Examination of any point on either part of the curve shows that the condition that its distance from the focus should bear the definite ratio e to its distance from the directrix, is still fulfilled.

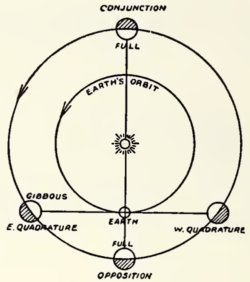
A remarkable property of the hyperbola is illustrated in the diagram below. For any hyperbola there is a pair of straight lines intersecting mid-way between the two limbs which approach closer and closer to the curve in either direction without ever touching it. These lines are the *asymptotes*.

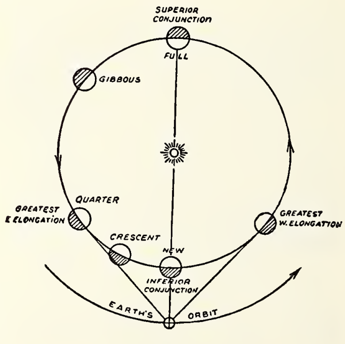


Any five points in a plane *define* a particular conic. This means that, except in some special cases, there is one and only one curve of the conic section kind that will pass through all these points.

(For a given ellipse or hyperbola, there are actually two possible foci, each with its corresponding directrix, which could take the place of F in the discussion above and yield the same conic, but this is mainly of mathematical interest. For an understanding of orbits, only one focus and one limb of the hyperbola need be considered.) (M.T.B.)

CONJUNCTION. When a planet appears in the same Right Ascension as the Sun and is in fact between the Sun and the Earth, it is said to be in *inferior conjunction*. If it is beyond the Sun, it is in *superior conjunction*.





Relative positions of Earth and an inferior planet (*upper diagram*) and a superior planet (*lower diagram*). Only an inferior planet goes through the same cycle of phases as the Moon.

ORION, from Johann Bayer's *Uranometria* (1603). The stars in the constellation are marked with Greek letters in order of apparent brightness. The dotted band on the left is part of the Milky Way. Two groups of three stars form the *Belt of Orion* and the *Sword of Orion.*

If it appears in the Right Ascension opposite to that of the Sun, it is in *opposition*. No inner planet can be in opposition, and no outer planet can be in inferior conjunction.

These distinctions pay no regard to the extent to which a planet may be 'above' or 'below' the Sun.

The diagram also indicates the positions of *quadrature* and *elongation.*

Planets in inferior conjunction may be too close for visual observation, not only because of the brightness of the nearby Sun, but also because their dark side will be facing the Earth, with at most a narrow crescent showing. On rare occasions there is a **transit** of Venus or Mercury at inferior conjunction.

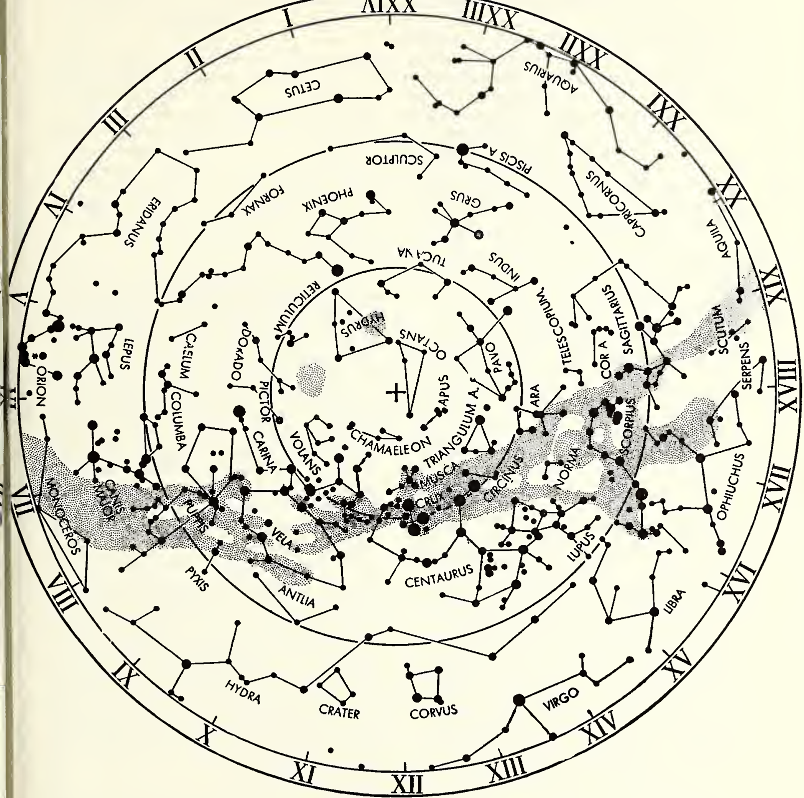
Planets may also be in conjunction with each other or with stars. This simply implies that they lie in the same Right Ascension as viewed from the Earth.

CONSTELLATIONS, STELLAR. The arbitrary groups into which the stars are divided for easy reference and identification. In most constellations, there is no real connection between member stars, which seem close together merely as a result of perspective. The constellations were named by the Ancients after various gods, animals etc., but it is vain to look for any resemblance in the patterns except in a few cases.

Stars in constellations are distinguished by small Greek letters prefixed to the name of the constellation, the letters being chosen from the Greek alphabet in the approximate order of brightness of the stars. Thus α Tauri is the brightest star in the constellation Taurus, but like many others it also has a proper name of its own, in this example *Aldebaran.*

(*See charts on next two pages.*)

THE NORTHERN HEMISPHERE OF THE SKY. Its centre lies above the Earth's North Pole, and very close to it is the Pole Star. The Milky Way stretches as an irregular band across the upper half of the chart. The brightness of the stars is indicated roughly by the sizes of the dots.



THE SOUTHERN HEMISPHERE OF THE SKY. The constellations near the edge of this chart can be seen from northern temperate latitudes at one time or another during the year. The Roman numerals around the rim give the Right Ascension of stars; for instance, the Southern Cross (Crux) and the gap in the Milky Way close to it known as the Coal Sack have a Right Ascension of just over 12 hours. (A photograph of this group is given in the article on Galactic Nebulae.)

CONTINUOUS SPECTRUM. A spectrum in which a continuous range of wavelengths (within certain limits) is found, either in emission or absorption. See **Spectroscopy**.

CONVECTION. The transfer of heat by movements of an unevenly heated fluid.

If a gas or a liquid is heated from below, the lower layers expand and so become less dense than the layers above. Consequently a circulation is set up, the colder, heavier layers of the fluid sinking down and driving the warmer, lighter layers to the surface. If the newly-risen fluid can cool at the surface it becomes denser again and presently sinks in its turn. Such flows are called *convection currents*.

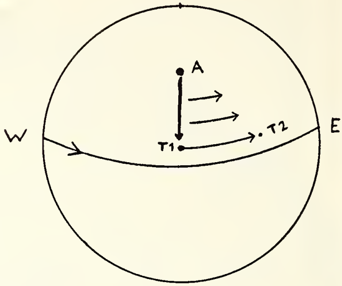
The granules seen on the surface of the **Sun** are probably due to convection.

COPERNICAN SYSTEM. The theory of the solar system propounded by the monk Nicolas Copernicus in 1543, in which he declared that the planets (and the Earth with them) revolve about the Sun and not about the Earth, and that the Earth rotates about an axis from West to East. The accepted theory at the time was the **Ptolemaic System**, which held the Earth to be at the centre of the planetary orbits. The ideas of the Copernican System were not wholly new, and had been put forward by Aristarchus and other Greek philosophers in the 3rd century B.C., but did not find acceptance until many years later when Galileo, using a telescope, saw the crescent Venus go to full phase, which was not possible in the Ptolemaic System.

Copernicus' main treatise was dedicated to Pope Paul III, and he had received great encouragement and support from the Church. After his death his ideas caused so much uninformed controversy among the laity and disturbed the faith of so many who were unable to reconcile the theory with Scripture, that it was declared false by the Church and became prohibited reading.

COPERNICUS. One of the larger craters of the **Moon**, named after the sixteenth-century astronomer Nicolas Copernicus, the originator of the **Copernican System**.

CORIOLIS FORCE. The 'force' that deflects a projectile during its flight across the surface of the Earth, to the right in the northern hemisphere and to the left in the southern. It is not a true force at all, but an effect due to the rotation of the Earth, and applies generally to all particles travelling across a rotating surface.



Consider a projectile fired in a direction due North from a gun on the equator. In addition to its muzzle velocity it will retain an eastward velocity which it shares with the gun and all things on the ground nearby, because all these things are rotating to the East with the Earth's surface. In the absence of external forces the projectile must keep all its eastward velocity, but as it moves North the rotational speed of the ground under it lessens, and the projectile will draw ahead of the ground in its eastward motion. By the time it falls it may have deviated to the East by several miles, as if a force had acted on it sideways, i.e. the Coriolis force. If the projectile is fired *towards* the equator, it will fly over ground which is moving progressively *faster* to the East, and the projectile will fall to the West of the line along which it was fired. Allowance has to be made for this effect in all gunnery, and in ballistic missile direction. (M.T.B.)

CORONA, SOLAR. The outer envelope of the Sun. It has up to thirty times the diameter of the Sun itself, and contains highly ionized gases, including gaseous iron, nickel and calcium, at a temperature of some 1,000,000° C. See **Sun**.

CORONAGRAPH. A telescope in which a circular disc is used to create artificial eclipses

of the **Sun** by blocking the light from the photosphere. It enables solar prominences and the corona to be photographed at any time. Before its invention in 1930 this could only be done during **eclipses**.

CORPORAL. A surface-to-surface tactical ballistic **missile** of the U.S. Army.

COSMIC RAYS. Extremely fast particles continually entering the upper atmosphere from interstellar space.

Ions are being generated all the time in the air to ground level. For ions to be formed, a considerable amount of energy must be given to the parent atoms, and at atmospheric temperatures such energy can only come from some sort of 'ray': this may be either **electromagnetic radiation** of very short wavelength, or a stream of particles travelling at high velocity.

The amount of ionization of the air decreases downwards, e.g. in a mine shaft, and increases upwards. The ionizing rays are therefore most effective high above the Earth, and their origin is outside the Earth: hence the name '*cosmic* rays'. The observed ionization also increases very slightly from the magnetic equator to the magnetic poles. This shows that cosmic rays are affected by the magnetic field and that they must therefore be electrically charged particles, since neutral particles and electromagnetic radiation would not be so affected.

It has been found that cosmic rays are atomic nuclei which have very great energies because of their enormous velocities. The nuclei are mainly those of light elements, especially hydrogen and helium, but nuclei up to 60 times the mass of a hydrogen atom occur.

The origin of the rays is still in doubt. Most of them probably come from far outside the solar system, but a proportion of low-energy ones clearly come from the Sun, and energetic solar activity may considerably raise the amount of cosmic radiation for a short time. A solar flare on February 23, 1956, caused a great increase in cosmic radiation all over the world. As the Sun can produce the rays it is reasonable to suppose that many other stars can do so, and the rays originate all over the galaxy. It does not seem possible for the observed energies of some cosmic rays to be even remotely approached by emission from the stars, but a plausible theory has been formulated which attributes the acceleration of the particles to the slight magnetic field which is believed to exist in our galaxy.

The particles which enter our atmosphere are called the *primary* rays. None of them reach ground level themselves, but in colliding with atoms of oxygen or nitrogen at a height of ten miles or more they impart their energies to the fragments resulting from the collisions, and these fragments or *secondary* rays are what we observe at lower levels.

Primary cosmic rays have been registered by rocket-borne cloud chambers, **Geiger** and other tube counters, and in photographic emulsions. Trouble sometimes arises through the fact that a primary ray on striking the metal of the rocket releases a shower of 'spurious' secondary rays, and the equipment has to be arranged in such a way that real and spurious rays can be distinguished. Another danger arises from ionization by cosmic rays of the air inside the instrument section of the rocket, leading to sparking between uncovered high voltage terminals.

The biological hazards of cosmic rays in space vehicles are unlikely to be serious except for manned satellites that spend prolonged periods at moderate distances from the Earth and near the polar regions, where the radiation is densest.

COSMOLOGY. The general science of the Universe in all its parts, laws and operations, so far as they can be known by observation and scientific enquiry.

For more than two thousand years the theory of the Universe that was generally accepted was that formulated by Aristotle in the fourth century B.C. He made the first and, for many ages, the only attempt to systematize the whole amount of knowledge of nature that was accessible to mankind; for that reason, perhaps, his views were long regarded as authoritative and were held in great veneration.

In common with most of the Greek philosophers, he believed that the Earth was fixed immovably at the centre of the Universe. At a time when ideas about mechanics were extremely crude, it seemed absurd to suppose that the Earth could be in motion. He also held that the Universe was finite.

According to Aristotle motion in space was of three kinds: motion in a straight line, motion in a circle and motions which are a

combination of these. The Universe being finite, motion in a straight line could not continue for ever. The circular motion is the only motion which has neither beginning nor end. The fixed stars and planets must consequently have circular motions.

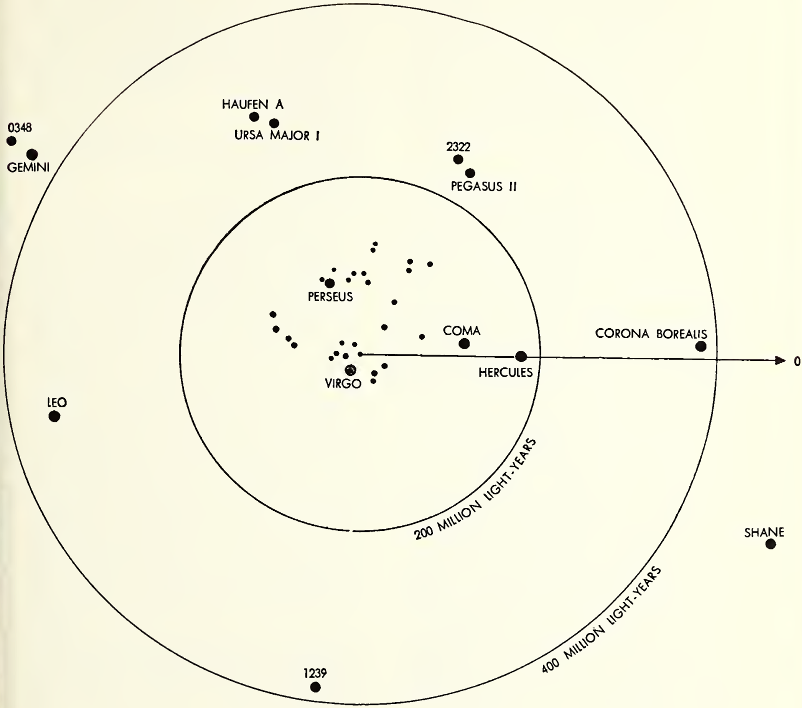
The world we inhabit was held to be made of the four simple elements, earth, air, fire and water; they possessed the tangible qualities, hot or cold, which were active, and dry or moist, which were passive. Because simple bodies have simple motions, the four elements tend to move in straight lines; thus earth tends downwards, fire upwards. There must be another element, said Aristotle, to which circular motion is natural. As circular motion admits of neither up nor down, this element can be neither heavy nor light; as it is without beginning or end, it must be incapable of increase or change. This superior element was called the aether, and must be more divine than the other four elements, being eternal and changeless. The stars, being spherical and eternal, were supposed to be made of the aether.

The fixed stars were supposed to be attached to a crystal sphere, which made one rotation each day. The seven moving stars or planets (the Sun, Moon, Mercury, Venus, Mars, Jupiter and Saturn) were each attached to separate spheres. The motion of each of these spheres was transmitted to the next inner sphere by a system of intermediate reacting spheres, there being no void or empty spaces between the spheres. The whole space from the fixed stars to the Moon was filled with the various spheres. The aether occupied the whole of this region, which was eternal and unchanging. Below the Moon was the terrestrial region, the home of the four elements, subject to ceaseless change through the strife of the elements and their continual mutual transformation. In this region of change and strife the shooting stars, meteors and comets appeared. Shooting stars and meteors were attributed to exhalations, one of a vaporous nature arising from the water on the Earth, the other dry and smoke-like rising from the Earth, which took fire when they were caught in the rotation of the inner sphere. Comets were explained as exhalations rising from below and catching fire.

The Aristotelian conception of the Universe has been briefly described because it dominated men's minds over many centuries, for far longer than any other cosmological theory has done. It was not without its difficulties, for its ability to explain the actual motions of the planets was very limited. The great changes in the brightness of the planets, and particularly of Venus and Mars, could not be explained if the distance of each planet from the Earth remained the same. To attempt to account for these changes in brightness and also to provide a better representation of the motions of the planets as observations of their positions accumulated, various ingenious mathematical theories were developed, based upon a combination of circular motions. These were looked upon merely as geometrical representations; there was no insistence on their physical truth.

The reaction against the cosmology of Aristotle was commenced by Copernicus, in the 16th century, who advanced the theory that the Sun instead of the Earth is at the centre of the Universe and that the Earth is merely one of the planets revolving round it as a satellite. The diurnal motion of the stars was attributed to the rotation of the Earth on its axis, the sphere of the fixed stars being brought to rest. The heliocentric doctrine of Copernicus was not a mere hypothesis, as the cosmology of Aristotle had been, but a theory worked out in detail to account for the motions of the planets. Two important consequences followed from it. In the first place, it necessitated a considerable enlargement in the size of the Universe; relative changes in the positions of the stars, as the Earth moved round the Sun, were not observed; it followed that the sphere of the fixed stars must lie far beyond the orbit of Saturn, instead of just beyond, as Aristotle had supposed. In the second place, when once the sphere of the fixed stars had been brought to rest, it was no longer necessary to suppose that the stars were all the same distance.

Though the Copernican theory was slow in gaining acceptance, because it was at that time such a revolution in thought, the fundamental ideas of the theory of Aristotle were gradually undermined. The careful observations by Tycho Brahe of the bright new star, which suddenly blazed forth in 1572, enabled him to prove that it was much more distant than the Moon, in the region, therefore, where according to Aristotle no change could take place. Tycho Brahe, from his observations of the great comet of 1577, concluded



THE DISTRIBUTION OF GALAXIES IN SPACE. Each of the smaller dots represents associations of 50 galaxies or fewer. The larger dots stand for clusters containing more than 50 galaxies. On this scale, the entire local group of some twenty galaxies, including Andromeda and our Milky Way Spiral, is contained in the small central dot. The line from the centre indicates 0° of galactic longitude. Some of the clusters are above, and others below the plane of our own galaxy. The true diameter of the region covered by this diagram is approximately 2,400,000,000,000,000,000,000 miles (two thousand four hundred trillion or, according to American usage, 2.4 sextillion miles).

(After J. Neyman and Elizabeth Scott, from 'Scientific American'.)

that it was moving round the Sun in a circular orbit outside that of Venus, and therefore also in the region where no change could occur. The Aristotelian notion that comets were exhalations from the Earth in its atmosphere was also disproved, and the idea of solid spheres was put an end to; as Kepler afterwards said, 'Tycho destroyed the reality of the orbs'. The next blow to the old ideas came when Kepler showed that the orbits of the planets were ellipses, having one focus at the Sun, so that the belief that the celestial bodies must have circular motions had to be abandoned.

The final death-blow to the system of Aristotle came early in the 17th century, when the recently invented telescope was turned on the heavens. The discoveries by Galileo of sunspots and the Sun's rotation, of the four major satellites of Jupiter which revolved around it as a parent body, and of the phases of Venus and Mars, firmly persuaded him of the correctness of the Copernican theory, which he vigorously championed in his writings. Galileo, by his refusal to accept statements merely on the authority of others and by his insistence on the necessity of appealing directly to observation, laid the foundation of rational scientific method.

In 1718 Halley found that some of the brighter stars were in motion, so that the stars could no longer be regarded as fixed. In 1783, William Herschel, from a study of the motion of a few of the brighter stars, proved that the Sun itself is in motion. The view that the stars extend outwards to great distances and that differences in brightness were due primarily to differences in distance had gradually come to be accepted. The Sun could therefore no longer be regarded as the centre of the Universe. So first of all the Earth and then the Sun had been displaced from occupying the proud position of the centre of the Universe.

The formulation by Newton of the hypothesis of universal gravitation; the first attempt to describe the structure of the Universe; and the results of modern observations, which have shown that space is occupied by a vast number of galaxies extending beyond the present limits of observation, are described in the article **Astronomy**. These results are of fundamental importance for modern cosmological theories.

Over 130 years ago, Olbers called attention to a paradox, which followed in a logical manner from certain initial assumptions which appeared to be plausible. The assumptions were:

1. That the stars are distributed on the average uniformly throughout space and that the average intrinsic luminosity of the stars is the same in all regions of space.

2. That the average spatial density and the average luminosity of the stars do not change with time.

3. That there are no large systematic movements of the stars but that their motions are in random directions.

4. That space is Euclidean or, in other words, that it has everywhere the properties with which we are familiar in everyday life.

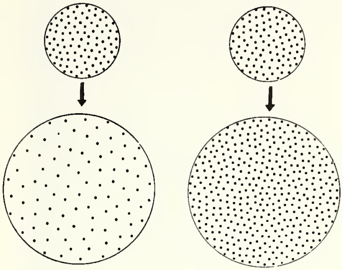
Suppose a series of large spheres to be drawn around any arbitrary point as centre, so that the difference between the radii of consecutive spheres is constant. The volumes of the successive spherical shells are proportional to the squares of the radii of the shells. Because of the uniformity in the spatial density and average luminosity of the stars and because these quantities do not change with time (so that we are not concerned with the fact that in looking outwards into space we are looking backwards in time), each shell must contribute an equal amount to the intensity at the centre. As we can add shells without limit, the total intensity of light at the centre must be infinitely great, which experience shows not to be correct. Therein lies the paradox. The paradox still persists if, in place of stars, we submit galaxies, in the light of our current knowledge of the Universe. It can be shown that the paradox persists even if space is not assumed to be Euclidean, provided only that it is homogeneous. It is not even essential for space to be infinite; the paradox will still hold for a finite but un-bounded non-Euclidean space.

The assumptions on which the paradox is based require to be closely examined. All observational evidence is in support of the assumptions that the galaxies are distributed on the average uniformly through space and that the average intrinsic luminosity is the same in all regions of space. But we are on much less sure ground when we consider the further assumption that there has been no change with time in either the spatial density or the average luminosity.

If the Universe has a finite age, light can reach us at the present time only from galaxies that are within the distance that light can travel in the time that has elapsed since the Universe was born. The number of spherical shells in Olbers' argument would in that case be finite, instead of infinite, and the paradox would then no longer exist. If, however, we retain the assumption that the average spatial density and luminosity of the galaxies do not change with time, we must drop the assumption that there are no large scale motions, for the paradox can be avoided if the contribution to the total intensity provided by the distant galaxies is much below the estimate of Olbers. This is possible, when the other assumptions are retained, only by one cause known to physics: the **Doppler** displacement of light. If the distant galaxies are receding rapidly, the radiation received from them is much reddened and is thereby reduced in intensity. If the velocity of recession is large enough, the reduction may be sufficient to reduce the total intensity of the radiation to a finite amount.

Thus there appear to be only two possible ways by which the paradox can be avoided. It is necessary to assume either that the Universe has a finite age, or that it is expanding, or that both of these statements are true. This conclusion is, indeed, subject to the proviso that the known laws of physics apply throughout the Universe. We have no reason to believe otherwise, though one modern cosmological theory has in fact been based upon the particular assumption that the frequency of a photon of light diminishes with time at a rate proportional to the lapse of time.

That the Universe is expanding is the natural interpretation of the observed Doppler displacements of the lines in the spectra of the distant galaxies, which increase proportionally with their distances. After the general theory of relativity had been formulated, it was applied to the Universe as a whole. Einstein and the Dutch astronomer, de Sitter, each formulated mathematically possible universes, which were static, in the sense that they would remain essentially unchanged with the lapse of time. There was an important difference between the two models. In de Sitter's universe, there would be an apparent recession of remote objects, which would not occur in Einstein's universe. But de Sitter's universe could only exist if it contained no matter. The difference between the two models has been summed up in the statement that Einstein's model contained matter but no motion whereas de Sitter's contained motion but no matter.



EVOLUTIONARY AND STEADY-STATE THEORIES of the Universe represented diagrammatically. The two top circles are portions of the Universe at the same time, with galaxies (black dots) scattered uniformly through them. Recession of the galaxies spreads them over a larger volume (left). The steady-state theory supposes that meanwhile new galaxies come into being so that, in spite of the expansion, the mean density of the galaxies remains unchanged. One of the chief tasks of modern astronomy is to find ways of testing these views with observational evidence.

It was later proved, however, that a static universe in accordance with relativity theory would not be stable. The slightest disturbance would cause it to depart from its static condition; it must either expand or contract. The interpretation of observation is that it is expanding.

Now suppose that the Universe has existed only for a finite time. Going backwards in time, the galaxies get nearer and nearer to us and to each other. We eventually reach a state in which they were crowded together into a comparatively small region of space. If the expansion has been at a uniform rate, this occurred several thousand million years ago. What produced this state and how the expansion began are matters for speculation. Lemaitre supposed that the Universe was created as a single primaeval atom, which contained all the matter that is now distributed throughout the Universe. This atom was

unstable and existed for an instant only. As soon as it was created it disintegrated into fragments, which in their turn broke up. The heavy unstable atoms with which we are familiar are supposed to represent the final stages of the universal disintegration of the past. After the initial disintegration the fragments flew outwards in all directions with great speeds. Another, somewhat similar, theory has been proposed in which the initial state of the Universe is supposed to have been a nuclear gas of extremely high density.

These theories require the Universe to have existed only for a finite time, measured by several thousands of millions of years. The future duration of its life must also then be finite, for the Universe, in the words of Codrington, can be likened to a clock that has been wound up and is running down. The stars continue to radiate by drawing on their store of atomic nuclear energy; in time this energy will all have been radiated and the Universe will then, in a sense, die.

The expansion of the Universe will carry galaxies one by one beyond the range of observation. After about ten thousand million years our galaxy, so far as observation can tell, would find itself alone in space. The Universe can consequently not have existed for an infinite time unless there has been a progressive creation of matter followed by the formation of galaxies. It is the view taken by what is termed the steady-state theory of the Universe. Observation supports the view that the galaxies are distributed on the average uniformly through space and that their intrinsic luminosity is the same in all regions of space. The Universe must then present the same aspect from every point except for local irregularities. This is termed the *cosmological principle.* A further assumption can be made, viz., that the Universe presents the same aspect from any place at any time, which is called the *perfect cosmological principle.* If this principle holds, the Universe must have existed for an infinite time. But inasmuch as the progressive expansion must result in a progressive reduction in the mean density of matter in the Universe, a progressive change would take place in its appearance unless there is a continuous creation of matter at a rate sufficient to compensate for the reduction in density. It will necessarily follow also that the Universe will exist for an infinite time in the future.

The matter that is created, presumably in the form of hydrogen atoms, will gradually aggregate into local clouds from which galaxies and stars will evolve, these galaxies balancing those that pass beyond the range of observation. The rate of creation of matter required to maintain the steady state is extremely small and cannot be detected by observation. The question arises whether there is any possibility of observational tests by which a decision could be reached whether the steady state theory or the initial exposure theory is correct. If the steady state theory is correct, then everywhere in the Universe there must be a mixture of galaxies of all ages; if the other theory is correct, than at any given distance the galaxies should be more or less of an age and, since looking outwards into space is looking backwards in time, the more distant the galaxy the younger its age should be. These differences may eventually enable a decision to be reached between the two alternative theories of cosmology, which are the only two under serious consideration to-day. (H.S.J.)

COUNT-DOWN. The procedure for phasing the various steps in the preparation and checking of a missile and ground station instruments up to the moment of firing. For a complicated research vehicle the count-down may extend over two or three days. The hours, and later the minutes and seconds remaining before the set time for launching are counted backwards and relayed by synchronized clocks and loudspeakers to different parts of the rocket station. During the final minutes the sequence of events is too fast and requires too much precision to be reliably controlled by human operators, and a computer takes over their functions.

CRAB NEBULA. A nebulosity in our galaxy of most unusual structure, with a **white dwarf** star at its centre. The spectrum of the surrounding gases shows a **Doppler** shift which indicates that these gases are streaming outwards at a speed of about 1,000 kilometres per second, presumably as a result of a violent explosion in the past. By working backwards on the basis of the present rate of expansion the date of the outburst can be calculated, and the Crab Nebula has been identified as the debris of a **supernova** whose appearance in a

position corresponding to that of the Crab Nebula was recorded in detail by Chinese astronomers in A.D. 1054.

The Crab Nebula is one of the most powerful radio transmitters in the sky. The central star may have a surface temperature of half a million degrees C., and probably consists largely of **degenerate matter.**

To the naked eye the nebula is a faint star in the constellation Taurus, on the edge of the Milky Way.

CRATERS, LUNAR. The numerous walled formations scattered over the surface of the Moon are known generally as craters; though, since they do not resemble terrestrial craters, such as Vesuvius, the name is not entirely appropriate. The largest are well over 150 miles in diameter whereas the smallest are tiny pits below the limit of visibility. (See **Moon.**)

CREEP. A gradual deformation of ordinarily rigid materials. Creep occurs in the metal of aircraft hulls when it is weakened by excessive heat generated by air resistance at high speeds. A form of very slow creep may be noticed on the lead roofs of old churches, the lower parts of each strip having thickened at the expense of the upper parts.

CRITICAL ANGLE. The greatest angle of incidence for which refraction of a ray travelling from one medium into an optically less dense medium is possible. For greater angles of incidence the ray will be totally *reflected.* (See **Refraction.**)

CRITICAL FREQUENCY. The frequency at which radio waves transmitted vertically change from penetrating an ionized layer to being reflected back to the Earth's surface. Communication with bodies moving above the ionized layers must be made at frequencies above the critical frequency.

CRITICAL TEMPERATURE. Pressure raises the boiling point of liquids. Many gases can therefore be liquefied by pressure alone at temperatures at which they are still gaseous under normal pressure. If the gas is, however, above its *critical temperature*, no amount of pressure can liquefy it.

CUSPS are the pointed ends of a crescent. The cusps of the crescent Moon, Mercury or Venus always point away from the Sun.

CUT-OFF RECEIVER. A small radio set carried within a missile or high altitude rocket which is operated by radio command from the range-safety officer. If the tracking devices indicate that the rocket will stray from the range under continued operation of thrust, a signal is transmitted which is picked up and decoded by the cut-off receiver. Relays are then activated to stop the flow of propellents so that the vehicle will fall within the range.

D

DATE LINE. At any one moment, two calendar dates are effective simultaneously over different parts of the globe, separated by the *International Date Line*. The need for this will be seen from the following argument:

Let it be midnight exactly at Greenwich between, say, a Wednesday and a Thursday. Southend lies a few miles to the East, and is therefore a little nearer the rising Sun; the astronomical time at Southend is accordingly 0.03 a.m. on Thursday morning. At Whitehall, a shorter distance to the West, the time is 11.59 p.m. on Wednesday night. The confusion which a strict adherence to astronomical time would create is avoided locally by the use of **Zone Time**, but over greater distances it remains true that East of Greenwich it is Thursday and West of Greenwich it is Wednesday. On the opposite side of the globe it is noon. Noon on Wednesday or Thursday?

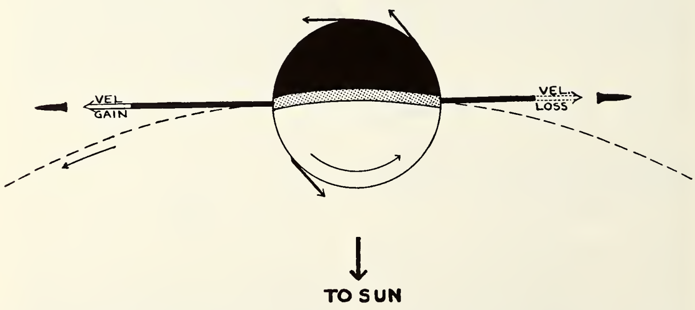
The Date Line resolves this difficulty by setting a definite though arbitrary limit to the areas over which the two calendar dates apply. The line follows the 180th meridian through the middle of the Pacific Ocean, diverging occasionally so as to include the whole of an island group on one side or the other. When crossing this line on a westerly course a day is 'lost', and the date must be advanced one day. The reverse is true for an easterly crossing. For one instant only each day, when it is midnight on the Date Line, does the whole world share the same calendar date.

DAWN ROCKET. An Earth satellite vehicle is often launched in an easterly direction so that the speed of *rotation* of the Earth's surface is added to the rocket's orbital velocity round the centre of the Earth, with a consequent economy in the weight of propellents required for a specific mission. In the same way, it is advantageous to launch an artificial planet at dawn in the direction of the Earth's *orbital motion*, so that the Earth's orbital velocity is added to the launching vehicle's orbital velocity round the Sun. This velocity is 18.5 miles per second is lost rather than gained in the case of a *dusk rocket*.

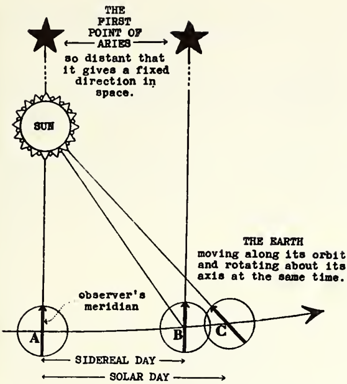
DAY. One *sidereal* day is the interval of time between two successive meridian passages of a star. One *mean solar day* is the interval between two successive meridian passages of the **Mean Sun**. A sidereal day is three minutes and fifty-six seconds of mean solar time shorter than a mean solar day. (See **Time Measurement**.) The *Civil Day* is based on the mean solar day, and is used for all ordinary purposes.

Tidal friction is very gradually slowing down the rotation of the Earth. This is causing the day to lengthen by approximately one thousandth of a second per century.

DAYTIME SHOWER. A shower of meteors coming from the direction of the Sun, and therefore not visible at night. (See **Meteor.**) One of the first results of the continuous watch by radio-echo methods was the discovery of the extraordinary activity of the daytime radiants during the summer months. From May to September there is a continuous succession of active streams, with hourly rates



DAWN AND DUSK ROCKETS. Their velocity gain or loss is independent of the latitude of the firing point. The smaller arrows indicate that an Earth satellite vehicle can benefit from the Earth's rotation irrespective of the time of day; but the effect decreases away from the equator and is zero at the poles.



of the order 20 to 80. Accurate velocities have now been measured, and the streams are known to have small orbits of high eccentricity, only slightly inclined to the ecliptic. The *o-Cetids* have an inclination of 34°, a period of 1.5 years and an eccentricity of 0.91; the other three showers have much smaller inclinations. This is perhaps the most remarkable feature of these showers, because the meteors can intersect the Earth's orbit at both nodes. Thus the *Arietids*, travelling in a small orbit with period 1.6 years and eccentricity 0.94, are seen again at the end of July as the night-time δ-*Aquarids*; the ζ-*Perseids*, which occur at the same time, have an orbit of similar size but smaller eccentricity of 0.78, and are seen again in November as the Southern Arietid stream. Whipple's study of the November *Taurids* led him to the expectation of the return of this shower in daylight hours in July, and the discovery of the daytime Taurids showed the correctness of this view. The Taurids have a period of 3.2 years, and, like the night-time Taurids, are related to Encke's Comet. (J.G.P.)

DECLINATION. The declination of any point on the Celestial Sphere is its angular distance from the celestial equator, expressed in degrees and positive if the point is North of the celestial equator, negative if it is South of it. Declination corresponds to Latitude on the Earth (but see **Celestial Sphere**).

DEGENERATE MATTER. A tremendously dense form of matter that occurs in **white dwarfs.**

In normal **atoms**, relatively large distances separate the nucleus from the electrons that encircle it. The atoms of degenerate matter have been stripped of their orbital electrons, and the nuclei are packed close together. The volume of a nucleus is an insignificant fraction of the volume of the whole normal atom, but virtually the whole of the atom's mass resides in the nucleus. The density of matter consisting entirely of nuclei is therefore very high. In the white dwarfs it can be about 36 million times that of water, so that 1 cubic centimetre of such matter would weigh over thirty tons at the surface of the Earth; and much higher densities are theoretically possible. Matter in this state is called *degenerate* because it no longer has any of the chemical and very few of the physical characteristics of ordinary substances. It cannot exist except under tremendous pressure. In the white dwarfs, this pressure is maintained by vast gravitational forces.

DEGREE OF ARC. A unit for measuring angles. A rotating line sweeps through 360 degrees of arc in one complete revolution. Each degree is subdivided into 60 *minutes* of arc (60′), and each minute into 60 *seconds* of arc (60″). A right angle contains 90°. (See also **Radian.**)

DEIMOS. The outer satellite of **Mars.** It is even smaller than **Phobos,** with an estimated diameter of only 5 miles, and is thus a difficult object to observe even when Mars is near opposition.

From any point on the surface of Mars, Deimos remains visible for two and a half days at a time, and during that period goes through all its phases twice.

DENSITY. The density of a given substance is its mass per unit volume. Its numerical value depends on the units of mass and length that are employed. In the centimetre-gram-second system the density of water is unity,

i.e. 1 cubic centimetre of water weighs 1 gram. The density of the Earth is about $5\frac{1}{2}$, while stars range from less than a millionth to many millions.

DIAMETER. This is a measure of the size of a circular or spherical body. It is the length of the longest straight line that can be drawn within the body, and passes through its centre. The *apparent diameter* of a body is the angle subtended by the body's diameter at the eye of the observer. Thus, the Moon is rather over 2,000 miles in diameter, but its *apparent* diameter as seen from the Earth is about half a degree.

The apparent diameters of virtually all stars are too small for the disc to be seen or photographed with even the largest telescope. All stars should therefore appear as points in photographs, and variation in the sizes of their images is a purely photographic effect owing entirely to differences in brightness.

DIFFRACTION GRATING. An alternative to the **prism** for forming a **spectrum** from light containing different wavelengths. See under **Spectroscopy.**

DIFFUSE SERIES. A series of very hazy lines in the spectra of sodium and potassium.

DIONE. One of the satellites of **Saturn.** It is the fourth satellite out from the planet, and with a diameter of about 700 miles is the fourth largest. It completes one revolution round Saturn in rather less than 3 days.

DIP OF HORIZON. The angle by which the horizon appears below the true horizontal direction as viewed by an observer above ground level. (See diagram under **Altitude.**)

DISCOVERER. The name given to a family of U.S. artificial satellites, including the first to go into a circum-polar orbit.

DISTANCE. Astronomical distances are expressed in the astronomical unit (A.U.), the **light year**, the **parsec** and in terms of **parallax.**

	miles (millions)	*Astron. Units*	*Light Years*
1 ASTRON. UNIT . . . . =	92.9	1	8.3 *light minutes*
1 LIGHT YEAR . . . . =	5,880,000	63,300	1
1 PARSEC . . . . =	19,150,000	206,000	3.26

DISTANCE MODULUS. A convenient method of expressing large distances. (See **Magnitude.**)

DOPPLER EFFECT. The apparent change of wavelength of light (or any other form of wave motion) when the source and the observer are in motion relative to one another.

The following analogy will illustrate the principle. Suppose that a ship is at anchor in a sea-way. If the waves are regular, a certain number of them will pass under the ship during a given interval of time. If the ship were moving directly into the waves, it would encounter more than that number during the same interval, and if it were moving with the waves it would encounter fewer. The frequency of the waves as observed from the ship would vary according to the ship's motion, and so would their wavelength (see **Wave Motion**).

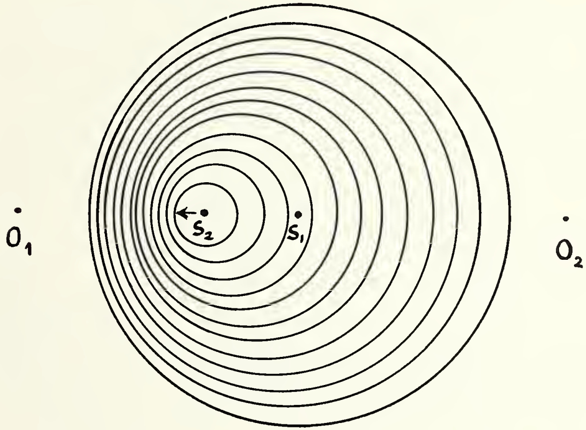
Similarly in the case of light from a star, if the relative motion between the star and the Earth is such that the star may be said to be approaching the Earth (or the Earth approaching the star) a terrestrial observer encounters more light waves per second, i.e. the frequency of the light waves will seem to have increased and the lines of the spectrum will have shifted towards the violet end. For a receding star there will be a similar shift towards the red side of the spectrum (see **Red Shift**). This displacement of the spectral lines can be accurately measured, and the

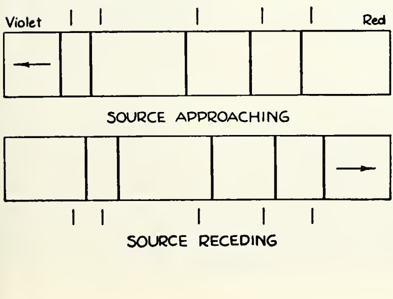
relative velocity of approach or recession calculated from it.

In certain cases the Doppler effect may also be used to detect *rotation* of a star. If the rotation is sufficiently rapid, the relative velocity of the edge or *limb* of the star which is turning *towards* the Earth will differ from that of the limb which is turning *away* from the Earth. The spectral lines in the light from these two limbs will therefore be displaced in opposite directions along the spectrum, while the light from the central part of the star's disc will remain unaffected. This will bring about a broadening of the spectral lines (see **Spectroscopy**). This principle is also applied to some eclipsing binaries (see **Binary Star**).

Exactly the same method is used in **Radio Astronomy** to deduce relative velocities from changes in the frequency of radio emissions whose true frequency is already known from other considerations.

DOPPLER RADIO. A device for tracking the flight of a missile, based on the **Doppler effect**. A transmission is made from a ground station at a constant frequency. This reaches two or





THE DOPPLER EFFECT. The diagram above shows a source of waves moving from S_1 to S_2. The outermost circle represents the wave that was emitted when the source was at S_1; the innermost circle stands for the wave emitted from S_2. The waves encountered by an observer at O_1 will be much more closely spaced (i.e. their frequency will be higher and their wavelength shorter) than those encountered by an observer at O_2. For light waves, this shift of frequency is revealed by the spectrum. Five spectral lines are chosen in the diagram on the left to illustrate this point; the marks above and below the spectra indicate the normal position of the lines.

three other ground stations (a) directly, and (b) after having been picked up and re-transmitted by a repeater unit in the missile. At each of the receiving stations a Doppler shift will be found to have altered the frequency of the transmission received via the missile, and from this the velocity of the missile relative to the station can be calculated. Three such relative velocities suffice to determine the path of the vehicle, and the necessary computation by triangulation methods is done by an electronic computer at such speed that the results can be used for guidance of the missile.

DOUBLE STAR. See **Binary Star**.

DOUBLET. Originally used to describe a close pair of lines in a spectrum. In spectra of many atoms (e.g. sodium) the strongest series is a series of doublets. The term is also used for close pairs of energy levels in atoms that are related in a particular manner. (See **Spectroscopy**.)

DOVAP stands for a missile tracking method based on the **Doppler effect**, velocity and position. See **Doppler Radio**.

DRACONIDS. See **June Draconids** and **October Draconids**.

DRAG. See **Air Resistance**.

DUSK ROCKET. See **Dawn Rocket**.

E

E LAYER. An ionized region of the Earth's atmosphere at a height of about 70 miles. It can reflect radio waves. See **Ionosphere**.

EARTH. The Earth, our home in space, is one of the group of inner planets. Apart from its exceptionally high mean density, 5.52 times that of water, it is quite unremarkable from an astronomical point of view.

ORBIT. The Earth revolves round the Sun at a mean distance of 93,000,000 miles, the perihelion and aphelion distances being respectively 91.4 and 94.6 million miles. The orbital eccentricity is 0.017, less than that of any other major planet except Venus and Neptune. The mean velocity is 18.47 miles per second.

ROTATION. The axial rotation period is 23 hours 56 minutes, and the inclination of the axis 23° 27′.

The rotation period is known with high accuracy, and in fact modern quartz clocks are better timekeepers than is the Earth. Small fluctuations in period occur. There is also the almost inappreciable lengthening of the day due to the tidal pull of the Moon (see **Tidal Friction** and **Tides**).

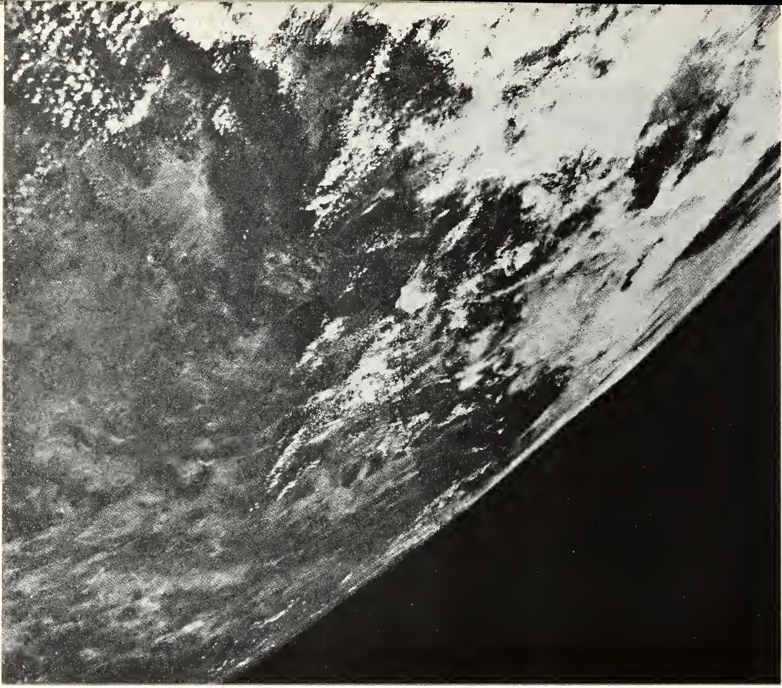
MASS AND DIMENSIONS. The equatorial diameter of the Earth is 7,927 miles; the polar 7,900, giving a polar compression of 1 part in 296. The **escape velocity** is 7 miles per second. The Earth is thus the largest of the inner group of planets, though only very slightly superior to Venus. Its mass is 6,000,000,000,000,000,000,000 tons.

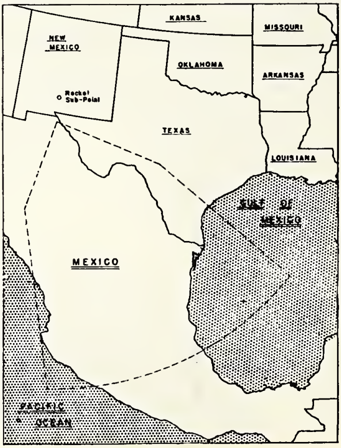
CONSTITUTION. Although we live on the Earth's surface, our knowledge of the inner composition of the globe is still scanty. Studies of earthquake waves indicate that there is a core of liquid iron or nickel-iron perhaps 4,000 miles in diameter, overlaid by a layer of stony material which is in turn overlaid by a layer of peridotite. The actual crust is less than fifty miles thick, and is made up largely of granite and volcanic rocks.

Pressures inside the Earth are tremendous (10,000 tons to the square foot at only 25

THE EARTH FROM A HEIGHT OF 100 MILES. The narrow dark area at upper left is the 65-mile wide Gulf of California. The aspect camera which took this picture from a rocket during flight used infra-red filters to cut the haze. The distance from the curved horizon to the lower edge of the picture is approximately 900 miles. Small groups of clouds are seen drifting seemingly just above the ground.

(*U.S. Naval Research Laboratory*)





Approximately 600,000 square miles of the Earth — mainly in Texas and Mexico — are shown in this photo. Two photographs taken 30 seconds apart were combined to give this composite view; the photograph on the left was taken at 155 miles, that on the right at 138 miles. From the camera to the horizon is approximately 1,100 miles, and the section of the horizon shown spans about the same distance. A well-defined cold front extends from the right-hand corner and runs parallel to the curvature of the Earth which, incidentally, is the true curvature of the Earth.

(*U.S. Navy photo*)

miles). The central temperature is uncertain, but is probably only a few thousands of degrees.

The Earth is unique in the solar system in that it possesses vast oceans. It is true that the presence of oceans on Venus cannot be ruled out, but Mars is certainly devoid of them.

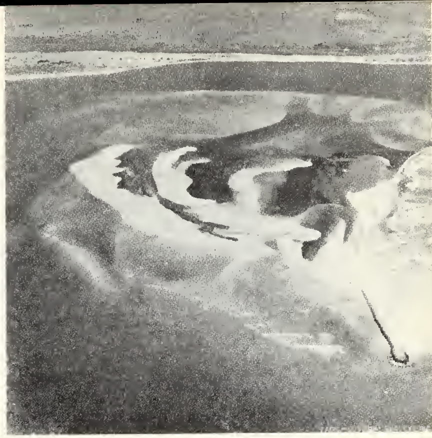
ATMOSPHERE. Since the Earth's escape velocity is 7 miles per second, the planet has retained a considerable atmosphere, though our present mantle is probably not the original one. The bulk of the air is made up of nitrogen (78%); oxygen accounts for 21%, and other gases are present in smaller quantities.

The abundance of oxygen in the Earth's atmosphere has probably been built up gradually by green plants which absorb carbon dioxide and release oxygen. The composition of the atmosphere has thus conditioned the forms of life found on Earth, and has itself been conditioned by them. (See **Atmosphere**.)

THE EARTH AS SEEN FROM SPACE. Photographs taken from high-altitude rockets show the curvature of the Earth unmistakably, but we have no certain knowledge of what our world would look like if viewed from another planet. According to some investigators the albedo appears to be about 0.35, much less than that of Venus, and the prevailing colour is likely to be bluish.

ORIGIN OF THE EARTH. Though many hypotheses have been advanced, we are still uncertain as to the manner in which the Earth came into being. The theory now favoured is that of von Weizsäcker, who supposes that it and the other planets were formed from material collected by the Sun during its passage through an interstellar cloud, but the whole question is still open (see **Origin of Solar System**).

AGE OF THE EARTH. From measurements of radioactivity in accessible rocks the age of the Earth's crust has been estimated at 2,000 million years. This means that the Earth can hardly be less than 3,000 million years old. (P.M.)



The surface of the Earth presents some unfamiliar aspects when seen from even a moderate height. These two photographs, taken from a conventional aircraft, are views of sand dunes in the Sahara, and of shoals on the Atlantic coast near Long Island. Studies of pictures such as these are helpful in the interpretation of rocket camera photographs taken from much greater heights.
(*Fairchild Aerial Surveys*)

EARTHSHINE. The faint illumination often visible on the 'dark' side of the crescent Moon. Objects on the part of the Moon not illuminated by the Sun are distinguishable by the light which is reflected from the sunlit side of the Earth. When the Moon is new, the Earth as seen from the Moon is in full phase and appears thirteen times as large as the Moon appears to us; it also has a considerably higher **albedo**, and therefore earthshine on the Moon is far more intense than moonlight on the Earth. When the earthshine is especially prominent we can see 'the Old Moon in the New Moon's arms'.

ECCENTRICITY is a quantity which defines the general shape of a curve (or **orbit**) of the kind known as **Conic Sections.** The eccentricity of an ellipse lies between 0 and 1, and the closer it is to 1, the more elongated the ellipse.

ECLIPSE. An eclipse occurs when one celestial body obscures another by passing in front of it. During an eclipse of the Sun, the Moon passes between the Sun and the Earth. During an eclipse of the Moon, the Earth is placed between it and the Sun and casts its shadow on the Moon. Planets occasionally eclipse stars, and the Moon does so constantly, but this phenomenon is always called an *occultation.* In certain **binary stars** the components eclipse each other as one moves across the line of sight from the Earth to the other. On rare occasions one of the inferior planets (Venus and Mercury) travels across the Sun's disc. This also is technically an eclipse, but as only a very small part of the Sun's surface is obscured the term *transit* is used for this.

An eclipse is said to be *partial* if part of the eclipsed body remains visible throughout; it is *total* if during one stage none of the eclipsed body can be seen; and it is *annular* (i.e. 'ring-shaped') if the eclipsing body is not large enough to block the light from the whole of the eclipsed body, so that during the middle of the eclipse only the central portion is obscured, leaving the entire rim to be seen.

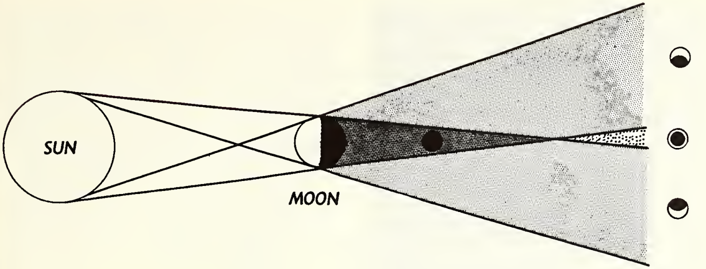
(Strictly speaking, of course, the Moon stays visible even when it is eclipsed, if only in dark outline. Moreover there can never be an annular eclipse of the Moon, because the diameter of the Earth's shadow at the distance of the Moon is still considerably greater than the diameter of the Moon itself.)

When a source of light that is not a point-source casts a shadow of an object, this shadow consists of two parts: the *umbra* or total shadow is the region completely cut off from the light, while the *penumbra* remains partly illuminated. This can be verified by holding a pencil above a sheet of paper under an ordinary light bulb. As the pencil is raised the *penumbra* broadens and the darker *umbra* in its middle shrinks and finally disappears altogether. When the Moon's shadow travels across the Earth, an observer in its penumbra will see a partial or annular eclipse of the Sun and one in its umbra will see a total eclipse.

Eclipses of the Moon can be seen simultaneously from all points on the Earth where the Moon is above the horizon, but they are of no great interest to astronomers. Eclipses of the Sun, on the contrary, have been of the highest value, chiefly because they allowed an examination of the Sun's corona and other phenomena which until the invention of the **coronagraph** was not possible at other times. For this reason, many expeditions have been sent to the narrow and often remote strips over which the tip of the Moon's umbra would pass during a solar eclipse, and all too frequently months of preparation have been foiled by a few clouds during the crucial moments of totality.

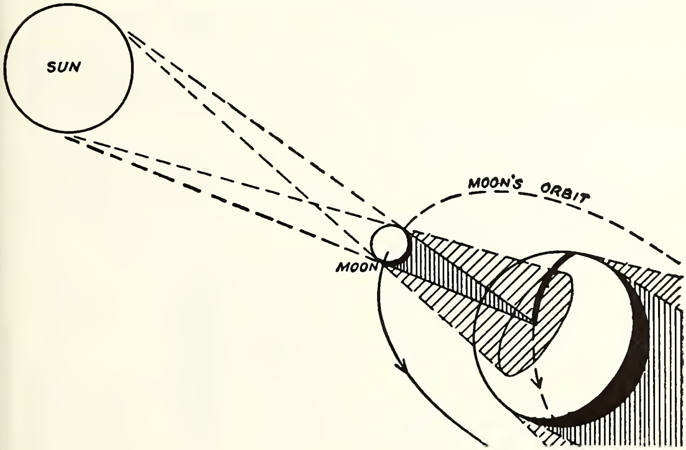
The nearer the Moon is to the Sun, the shorter the cone of its full shadow. When the Earth–Moon system is near perihelion this cone is generally too short to reach the Earth at all even if the Sun, the Moon and the Earth are exactly in line. A total eclipse is then impossible, and an annular eclipse will be observed.

A total eclipse begins at *first contact,* when the limb of the (inevitably *new*) Moon appears to touch the edge of the Sun's disc. There follows the partial stage during which the day grows dim as more and more of the Sun is obscured. Just before *second contact,* the beginning of totality, the contours of the leading edge of the Moon break up the vanishing crescent of the Sun into patches of light called **Baily's Beads.** They disappear again almost at once, and the *corona* flashes into view. A bright halo surrounds the hidden Sun, traversed by the coronal streamers and perhaps the vivid red arch of a *solar prominence.* The brighter stars shine in a dusky sky, and possibly also a comet near its perihelion. (See also **Sun.**)



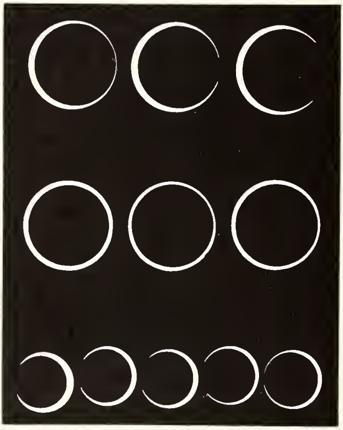
Above: THE MOON'S SHADOW. No part of the Sun's disc is visible to an observer within the dark cone of the Moon's total shadow or *umbra*, as indicated by the black circle. The other circles show how the Sun would appear from various positions within the half-shadow or *penumbra.*

Below: the track of an eclipse across the surface of the globe. As the Moon travels in its orbit and the Earth rotates under it, the Moon's full shadow traces out a curved track, usually from 50 to 100 miles wide, within which a total eclipse of the Sun can be observed.



After seven and a half minutes at the most the sequence of events is reversed. At *third contact* the Sun begins to re-emerge, at *fourth contact* the last of the Moon draws clear of its edge.

Eclipses permit very accurate determinations to be made of the Moon's motion and the **perturbations** that affect it. They have also made it possible to confirm a prediction contained in the Theory of **Relativity** that light is bent towards a gravitating body. To test this point, it was necessary to photograph stars whose light passes close to the Sun before reaching the Earth, and then check



Various aspects of the annular eclipse of April 7, 1940. (*Menzel*)

for any apparent change in the star's position. This was done successfully during an eclipse in 1919, when the displacement was found to agree almost exactly with the predicted amount.

It is not difficult to calculate the dates and paths of eclipses forwards or backwards over many centuries. Many historical events whose records mention an eclipse have thereby been dated.

Every 18 years and $11\frac{1}{3}$ days the sequence of eclipses repeats itself almost exactly. This interval is called a **saros** cycle, and has been known since the days of the Chaldeans. (M.T.B.)

ECLIPTIC. The intersection of the plane containing the Earth's orbit with the **celestial sphere**. It can also be defined as the apparent path of the Sun among the stars.

As the Earth moves in its orbit the position of the Sun relative to the star background changes, making one complete circuit of the sky in a year. It is of course immaterial that these background stars cannot be seen at the same time as the Sun, since their positions on the celestial sphere are known. The Sun lies in the plane of the Earth's orbit, and so its apparent path marks the ecliptic in the sky.

As the plane of the Earth's equator is inclined to that of its orbit at an angle of about $23\frac{1}{2}°$, the ecliptic is inclined to the **celestial equator** by the same amount. The points of intersection of the ecliptic and the celestial equator are occupied by the Sun at the *equinoxes*; the Sun reaches its furthest North of the equator at the *summer solstice*, and its furthest South at the *winter solstice*.

The other major planets of the solar system, and most of the asteroids also, have orbits lying in nearly the same plane as that of the Earth. They can therefore never be seen far from the ecliptic.

The constellations through which the ecliptic passes are called the Signs of the **Zodiac**. (R.G.)

ELECTROMAGNETIC SPECTRUM. The full range of wavelengths of **electromagnetic radiation.**

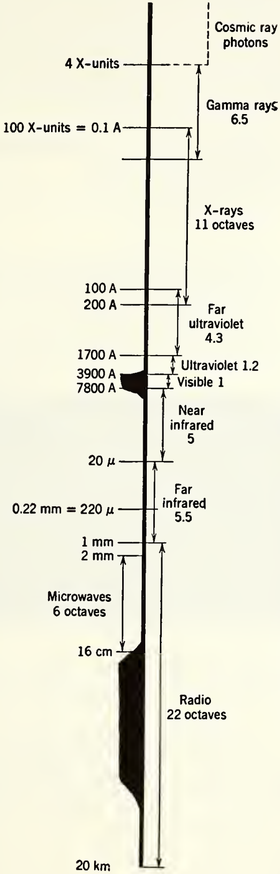
The character of this radiation changes markedly as the wavelength decreases. The longest waves are known as radio waves, with wavelengths of several kilometres, while the shorter ones include gamma-rays and X-rays. The whole spectrum is shown in the diagram.

The use of the word *spectrum* here extends the idea of the spectrum of light which a **spectroscope** can produce, but there is no single apparatus that can deal similarly with *all* forms of electromagnetic radiation.

ELECTROMAGNETIC WAVES. Periodic fluctuations in space of electric and magnetic fields which act in directions perpendicular to each other and to the line of propagation. (See **Wave Motion** and **Field.**)

Energy can be radiated through a vacuum in the form of electromagnetic waves. There is therefore no medium whose particles propagate such waves by their motion, and the only reason why this form of energy is called a wave motion is because it obeys all the basic *mathematical* laws that govern wave motion in a material medium such as water or air.

Radiated heat, light, radio and radar waves, X-rays and gamma rays are all electromagnetic waves of different wavelengths. A detailed list is given under **Electromagnetic Spectrum.**



THE ELECTROMAGNETIC SPECTRUM plotted on a logarithmic scale. The thickness of the solid black areas represents the extent to which the Earth's atmosphere is transparent to the corresponding wavelengths. (*After Menzel*)

In the absence of matter, all electromagnetic waves travel with the speed of light, which is almost exactly 300,000 km per second, a distance equal to seven and a half times the circumference of the Earth. They can be *refracted*, as light is refracted or 'bent' by a lens, and *reflected*, as in a mirror, and their direction of travel may be curved by a gravitational field.

Electromagnetic waves are created when an atom gives up energy by relaxing the orbits of one or more of its electrons, or by changes involving its nucleus (see **Atom**). They can also arise through the motion of electrically and magnetically charged matter.

There are occasions when they do *not* obey the mathematical rules of wave motion and behave in every way as if they were fast-travelling *particles*. The point is that, whatever happens, electromagnetic energy does follow certain rules and laws in a consistent way, and it is as unimportant to be able to *visualize* its nature as the precise shape of chessmen is unimportant to an understanding of the game of chess.

ELECTRON. A fundamental particle that exists in every **atom**. The mass of an electron is about 1/1840 of that of a hydrogen atom, and is therefore much less than the masses of the other common particles, the *proton* and the *neutron*, which are almost equal to the hydrogen atom. The electron however possesses an electrical charge as great as the charge of a proton, but negative whereas the proton's charge is positive.

The electron is the only particle outside the nucleus, or heavy central body, of an atom. It can be separated from the atom to which it belongs by friction, heat, radioactivity or any other form of energy which promotes ionization. It is then called *free*.

Although the number and distribution of electrons in an atom largely determine the latter's properties, the electrons themselves are not to be regarded as material particles like hard little spheres: they are not *made* of anything. Their effects can nevertheless be observed when they are in the free state. The familiar electric current is simply the flow of electrons along a wire or other conducting body. Electrical conductors are materials whose atoms offer very little resistance to an electron flow. Although an electrical current travels with the speed of light, the electrons

constituting it move relatively slowly, at a speed of the order of millimetres per second. In the same way, if a valve is turned on at one end of a long pipe containing water, the water begins to flow out of the other end practically at once even though it moves quite slowly in the pipe.

Electrons are responsible for the opacity of stars, which might be expected to be transparent as they are made of gas. In stars at temperatures similar to that of the Sun, light of any wavelength may be absorbed by bound electrons in atoms. Light with energy greater (i.e. wavelength less) than a certain critical amount is capable, not of causing an electron to change its orbit, but of removing it from the atom altogether. In doing this, the light is absorbed and may be re-emitted with a different wavelength. Light coming from deep down in a star is thus absorbed and re-emitted at a higher level, so that we see no light from the interior. In stars at very high temperatures, light is scattered by electrons which are already free, and this is sometimes the most important source of opacity. (R.G.)

ELECTRON DENSITY. The number of free electrons (i.e. those not bound to atoms) in unit volume. This is a quantity which is of interest in connection with stellar interiors, and with the Earth's **ionosphere**. The ability of the ionosphere to 'bend' radio waves and return them to the Earth is dependent directly on the electron density.

ELEMENT, CHEMICAL. One of over 100 substances which cannot be split up into simpler substances by chemical means. Elements combine chemically to form *compounds*, and the properties of a compound usually differ entirely from those of its constituent elements.

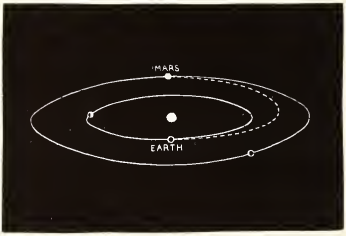
Of the known elements, about a dozen do not occur naturally and have been produced artificially in the laboratory. Many others are comparatively rare. The most common elements of the Earth include hydrogen, oxygen, nitrogen, carbon, silicon, sulphur, chlorine, iron, nickel, magnesium and aluminium. In addition to most of these, helium and to a lesser extent titanium are common in stars.

All neutral atoms of an element are alike. The radiation emitted by atoms gives rise to spectra (see **Spectroscopy**) from which they can be identified when chemical tests cannot be applied. Most elements have stable atoms, but some, like radium or uranium, undergo radioactive *decay* and change into other elements, the change being accompanied by a release of energy and particles that are fragments of an atom. (See **Atom.**)

ELEMENT, ORBITAL. One of six quantities necessary to define an **orbit.**

ELLIPSE. See **Conic Sections.**

ELLIPSE, TRANSFER. The path by which an interplanetary vehicle can transfer from an **orbit** about one body into an orbit about another. It is part of an ellipse; the point on this ellipse furthest from the first body should lie in the orbit about the Sun of the second body for the sake of fuel economy.



TRANSFER ELLIPSE from Earth to Mars. During the transfer both planets move (counter-clockwise in the diagram) along their orbits.

An acceleration is needed to embark on the transfer ellipse. By combining careful timing with a suitable acceleration or retardation upon reaching the second body's orbit, the vehicle could then either land on it, follow it, or circumnavigate it and return to the first body.

ELONGATION. (See diagram under **Conjunction.**) The difference in **Right Ascension** between an inferior planet (Mercury or Venus) and the Sun. It is usually measured in degrees of arc. The possibility of observing a planet depends on the darkness of the sky when the

planet is at a reasonable altitude, i.e. high enough not to be excessively affected by atmospheric vagaries. The sky darkness depends on the distance of the Sun below the horizon, and the elongation is thus an indication of the visibility of the planet. Superior planets are rarely observed when they appear close to the Sun, but the elongation of the inferior planets is of importance because it can never be great – not more than 47° for Venus, or 28° for Mercury. When these planets have elongations East of the Sun they can be seen in the evening sky; western elongations correspond to morning appearances.

EMISSION SPECTRUM. A spectrum consisting of bright lines, bands or a continuum emitted by a hot source. See **Spectroscopy**.

ENCELADUS. One of the smaller satellites of **Saturn**. It is the nearest but one to the planet; its diameter is about 300 miles and it takes 33 hours to describe one revolution in its orbit.

ENCKE'S COMET has the shortest revolution period of all the periodic comets – 3.3 years. Its perihelion lies within the orbit of Mercury, while its aphelion lies well out in the asteroid zone. The comet was discovered in 1786, and since 1819 it has been observed at each return to perihelion except that of 1944. Searches with the large telescopes on Mount Wilson before the returns of 1951 and 1954 resulted in its recovery seven months and ten months before perihelion respectively, while the comet was still in the outer half of its orbit. On the latter occasion the comet was barely of the twentieth magnitude at the time of its recovery! Nearly a year later, at perihelion, it exceeded sixth magnitude.

ENCKE'S DIVISION. A minor gap in **Saturn**'s outer ring.

ENERGY. The capacity for doing work. There are several kinds of energy to be considered.

KINETIC ENERGY or energy of motion. Any moving body possesses kinetic energy in proportion to its mass and to the square of its velocity:

$$\textit{kinetic energy} = \tfrac{1}{2}\,\textit{mass} \times \textit{velocity}^2$$

Examples: a cannon ball does work when it strikes a wall by breaking and moving the stones; a flywheel can continue to turn over a motor after the power supply has ceased; the kinetic energy of a meteor is dissipated in the form of heat, light, sound and radio waves as it is slowed down on entering the atmosphere.

POTENTIAL ENERGY. A body has potential energy by virtue of its position relative to a force that is acting on it. Examples: an object raised above the ground – the force acting on it is that of gravity, and if the object is allowed to fall it acquires kinetic energy and can therefore do work; a loaded spring – if it is released, it can do work by moving a body or driving a mechanism such as a clockwork; a piece of iron near a magnet – if it is permitted to move, it too will acquire kinetic energy, and it may pull another body with it.

RADIANT ENERGY. This is the energy inherent in electromagnetic waves. An outstanding example is the radiated energy of the Sun, which when it reaches the Earth does work by warming and ionizing the atmosphere, by heating the ground and evaporating water, by effecting the build-up of starch and sugars in green plants, and in countless other ways.

CHEMICAL ENERGY. More often than not this form of energy requires a small initial investment of work before it becomes apparent. Examples: the heat of a match applied to a sheet of paper will release chemical energy as heat of combustion; a small spark can initiate the explosion of a mixture of hydrogen and chlorine leading to the evolution of heat of combination.

NUCLEAR ENERGY. Of all the above forms of energy it is true to say that, *in a closed system, the total amount of energy remains constant*, no matter what changes may take place in the system. Nuclear energy, however, stems in part from the transformation of matter into energy. The quantity of energy that can be obtained from the destruction of a given amount of matter is given by the equation:

$$\textit{Energy} = \textit{mass} \times (\textit{velocity of light})^2.$$

ENERGY LEVEL. The distribution of the electrons in an atom among the various orbits they can occupy.

If an electron jumps from one orbit into another, smaller one, it loses energy which is emitted as radiation of a particular wavelength. An electron can also absorb radiated energy by jumping into a greater orbit. The first event will lower, and the second raise the energy level of the atom in which it occurs. The lowest energy level of an atom is called its *ground state*. (See **Atom** and **Spectroscopy**.)

ENERGY, ORBITAL. The sum of the potential and kinetic energies of a body revolving in an **orbit** about another body.

EPHEMERIS. A table giving the predicted positions of some body in the solar system for a succession of future dates.

EPOCH. In astronomy, an arbitrarily chosen moment in time to which measurements of position are referred. Owing to the **precession** of the Earth's axis, the equator shifts slowly, and with it the celestial equator. This causes the **Right Ascension** and **Declination** of a star to vary continuously, as these quantities depend upon the position of the celestial equator (see **Celestial Sphere**). The lines of Right Ascension and Declination drawn across star maps are therefore strictly correct only for the date or *epoch* for which they were drawn. The epochs commonly used are 1855, 1900, 1920 and 1950; and a position measured from an atlas is not completely specified unless the epoch is also quoted, so that suitable corrections may be made if necessary.

EQUATION OF TIME. See **Mean Sun**.

EQUATOR. The equator of a rotating sphere is the line joining the points on the surface which are equidistant from the two poles of the axis of rotation. The plane in which the equator lies cuts the axis at right angles in the centre of the sphere. At the equator, centrifugal force and angular velocity are greater than anywhere else on the surface of the sphere. (See also **Celestial Equator**.)

EQUINOX. A moment at which the Sun's centre crosses the **celestial equator** as seen from the Earth's centre. During its annual journey around the **ecliptic**, the Sun crosses the celestial equator twice. There are therefore two equinoxes each year: the *vernal equinox* occurs about March 21 and marks the official beginning of spring, while the *autumnal equinox* near September 22 marks the beginning of autumn. At those dates, day and night are of roughly equal length all over the Earth.

EROS. The first discovered of the minor planets which comes within the orbit of Mars; as it is of some size, with a longest diameter of 15 miles, it has proved very useful for determining the value of the astronomical unit. (See **Asteroids**.)

ESCAPE VELOCITY. The minimum velocity which will enable an object to escape from the surface of a planet or other body without further propulsion.

The escape velocity of the Earth is just over seven miles per second, or 25,000 m.p.h. Once a body moving upwards has exceeded this speed, its own momentum will carry it away from the Earth in a hyperbolic **orbit**, and it will never return under the influence of gravity. This is equally true of a light particle, such as an atmospheric molecule, and of a heavy missile. Escape velocity does not allow for air resistance, but in all practical cases the velocity will not be attained until heights are reached at which air resistance is so low that it can, for this purpose, be disregarded.

A few calculated escape velocities are given below, in miles per second:

Earth	7.0
Moon	1.4
Mercury	2.2
Venus	6.3
Mars	3.1
Jupiter	37.2
Callisto	0.9

EUROPA is the smallest of the four major satellites of **Jupiter**, having a diameter of 1,950 miles. It revolves in its orbit in about 3½ days.

It is a good reflector of light, and appears almost as bright as the larger **Io**. The escape velocity of only 1.3 miles per second indicates that it is incapable of retaining an atmosphere.

NGC 4594, the 'Sombrero Hat' galaxy – a vast spiral system of some 100,000,000,000 stars, seen edge on. (*Mount Wilson – Palomar*)

EXHAUST VELOCITY. The velocity with which the burnt gases leave the combustion chamber of a rocket. It is a measure of the performance of the rocket propellents – the higher their performance, the greater the exhaust velocity. It is also connected with the **specific impulse** by the equation:

$$\textit{Exhaust velocity} = \textit{specific impulse} \times g,$$

where g is the acceleration due to gravity. Typical values for exhaust velocities of modern propellents, at ground level, are 6,000 – 7,500 feet per second. These figures represent about half the theoretical maximum obtainable from normal chemical propellents. Atomic propulsion units may one day give exhaust velocities of 25,000 f.p.s. or more.

EXOSPHERE. The outermost region of the **Atmosphere of the Earth.**

EXPANSION OF THE UNIVERSE. A term which has been used to describe the apparent spreading apart of the **galaxies**, which constitute the largest units in the Universe. The rate of recession of each galaxy from our own is consistent with an expansion in all directions of the Universe as a whole and not merely of the matter in it. (See **Red Shift** and **Cosmology.**)

EXPLORER. The name given to a family of U.S. **artificial satellites**, including the first successful American one.

EXTRAGALACTIC NEBULAE. These are vast systems, composed at least partly of stars, which exist outside our own galaxy.

Three extragalactic nebulae are visible to the naked eye: the two **Magellanic Clouds,** which appear as luminous patches in the

TYPICAL SPIRAL GALAXIES. Those on the left have roughly spherical nuclei, and are denoted by an S. The three on the right are all *barred spirals* ('SB') in which the arms emerge from the ends of a straight bar through the centre. The small letters a, b and c indicate progressively more open spirals. (*Mount Wilson – Palomar*)

southern sky, and the **Andromeda Nebula**, visible as a hazy, faint star. A telescope reveals many more; their distribution seems asymmetrical, none being visible in the vicinity of the Milky Way, but this is probably a result of **galactic absorption**. In directions pointing out of the galactic plane vision is relatively unobscured by interstellar dust, and photographs taken with large telescopes show as many nebulae as stars.

The brighter nebulae have been assigned numbers in various catalogues. Thus the Andromeda Galaxy is M 31, being Number 31 in Messier's catalogue; there is also the New General Catalogue (NGC) and the Index Catalogue (IC). Not all objects listed in these catalogues are extragalactic: hazy objects and star clusters within our own galaxy are also included. The term nebula is now usually restricted to clouds of gas in the Milky Way system; those outside are generally called *galaxies*.

TYPES OF GALAXIES. Our own galaxy is thought to be a typical *spiral*, and the characteristics of the type are described under **Galaxy**. The Andromeda Nebula is another example. The two kinds of stellar populations found in spiral nebulae, Population I and II, are discussed under **Hertzsprung-Russell diagram**.

A spiral galaxy is usually in the form of a circular disc with a central bulge. The photograph of NGC 4565, a spiral which we see edge-on, shows this bulge or *nucleus* clearly. The nucleus consists of Population II stars, the disc round it of Population I objects; both rotate. Not sharing in the rotation, and distributed around the nucleus, is a halo of Population II stars and a few dozen **globular clusters**.

A rather different type is the **barred spiral**, in which the arms extend, not from a nucleus, but from the ends of a straight bar in the centre of the galaxy.

NGC 4565, a spiral galaxy seen edge on. Interstellar matter in the spiral arms obscures part of the nucleus.

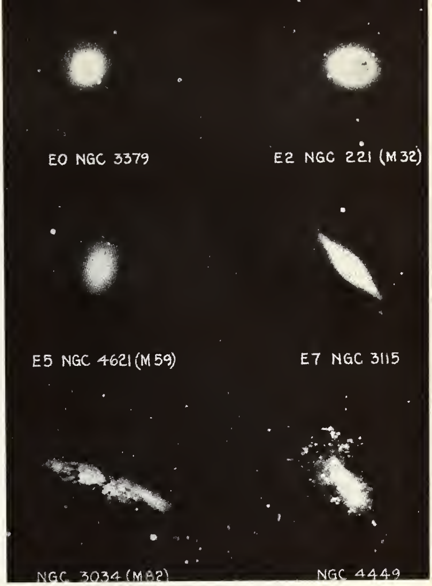
Elliptical galaxies are structureless agglomerations of stars. They look and are like the nuclei of spirals, consisting entirely of stars belonging to Population II, and being free from dust.

Irregular galaxies have no obvious symmetry. They probably contain objects of both populations. The Small Magellanic Cloud is a good example.

A large galaxy may contain over a hundred thousand million individual stars.

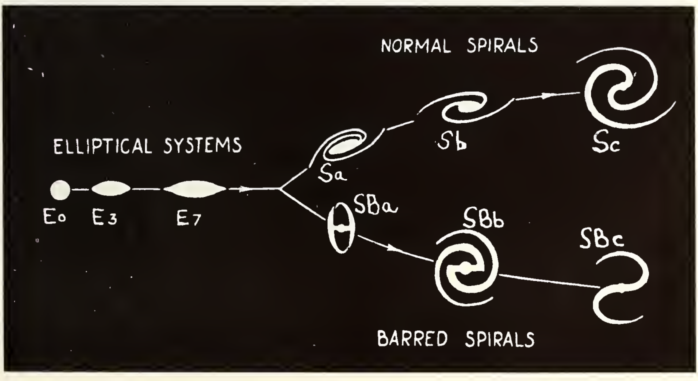
CLUSTERS OF GALAXIES. Many galaxies belong to clusters which have up to a thousand members. Our own galaxy is one of the *local group* of about twenty galaxies, including the Andromeda Spiral and its two elliptical companions as well as the Magellanic Clouds.

A rich cluster in the constellation *Coma* is notable for the absence of any galaxies showing spiral arms or interstellar dust. The density of galaxies in this cluster is so great that nearly all must have suffered many collisions with other galaxies. In such a collision the stars, which are tiny compared with the spaces between them, would pass through unharmed; but the interstellar dust and gas would undergo real collisions and be swept out of both galaxies, which could not then continue to form Population I stars from it.



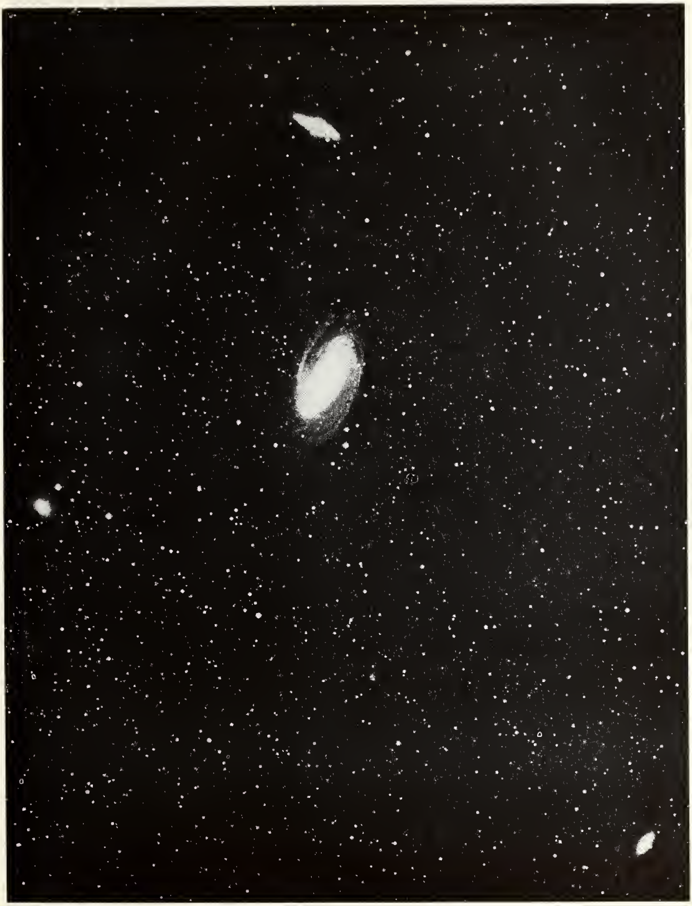
ELLIPTICAL AND IRREGULAR GALAXIES. Some of the foreground stars from our own Milky Way can be seen in front of the elliptical galaxies. (*Mount Wilson – Palomar*)

Below: a possible course of the evolution of galaxies.



TWO GALAXIES IN COLLISION. A spiral galaxy, seen more or less edge on, is moving through another stellar system of elliptical shape.

Even though a collision like this may take place at a combined speed of thousands of miles per second, it cannot be justly called a cosmic catastrophe. Because of the vast distances between individual stars within the galaxies, the two systems will pass through each other and emerge relatively unscathed. Collisions of stars must be rarer than the meeting of cannon balls in the hottest battle, and the powerful radio emissions received from these galaxies probably arise from the mingling of their interstellar material.



GALAXIES IN SPACE. A group of four stellar systems in the Great Bear constellation. The beautifully formed spiral of Messier 81 is near the centre of the picture; the others are elliptical galaxies, with the top one seen more or less edge-on. This group is about 7,000,000 light years distant.

(*National Geographic – Palomar Sky Survey*)

A CLUSTER OF GALAXIES in Coma Berenices. Each of the objects with fuzzy outlines in this picture is a galaxy containing many millions of stars; the local foreground stars of the Milky Way can be distinguished by their firm, circular outlines. Our picture is an enlargement of part of a photograph taken with the 200-inch Hale telescope; in the minute portion of the sky covered by it, over a hundred galaxies can be traced, but at a distance of about 80 million light years many of them are too faint for reproduction in print. Two galaxies in collision are at lower left.

DISTANCES AND MOTIONS OF THE GALAXIES. The spiral systems in the local group contain, among other types of star, Cepheid **variables**, supergiants, and quite frequent **novae**. The absolute magnitudes of these are known, and by comparing them with the apparent magnitudes we can estimate the distances. The Andromeda Nebula turns out to be well over half a million parsecs away.

The nearest cluster of galaxies apart from the local group is in the constellation *Virgo*. The very brightest stars in it, of absolute magnitude —7 and —8, can just be photographed as individuals, and again comparison with the measured apparent magnitude yields the distance, in this case five million parsecs. The distances of more remote clusters of galaxies are estimated by assuming that their brightest member *galaxies* (and not *stars* in a galaxy) are similar to the brightest members of the Virgo cluster.

Even the nearest galaxies are much too far away to show any **proper motion**, but the velocities along the line of sight from the Earth of distant galaxies are measurable with the spectroscope (see **Red Shift**). One and all are receding from us, and from each other, and the speed of recession increases in proportion to the distance; it is about 290 km per second for every million parsecs that separate the observed galaxy from us. For the most distant galaxies yet measured, this

A GROUP OF GALAXIES IN LEO. Four more dissimilar individuals would be hard to find: one is elliptical, one a normal spiral, and two are very different examples of barred spirals. The arms of one of the latter are drawn out, probably by the gravitational attraction of its neighbour.

(Mount Wilson – Palomar)

mounts up to one third the velocity of light – a truly staggering velocity. The fact that all the galaxies appear to move away from us does not mean that we are at the centre of some curious disturbance: a number of spots painted on a balloon would move apart in a similar way when the balloon was inflated without appearing to shun any one particular spot.

Some astronomers seem unable to accept the reality of the recession of the galaxies and have tried to find other explanations for the observed shift of the spectral lines, without success. **Radio astronomy** has on the other hand provided some confirmatory evidence. If the recession is real, and one naively extrapolates backwards in time, one concludes that about 3,500 million years ago the galaxies were all in a very small volume. This time is possibly significant, being similar to estimates of the ages of galaxies, stars, the Earth, and atoms.

ROTATION OF GALAXIES. In every spiral galaxy the rotation is such that the spiral arms trail behind the nucleus. Their spectra show the relationship between rotational velocity and distance from the centre. They demonstrate that the middle parts of the spirals rotate as rigid discs, but the outer regions lag behind more and more. The nucleus of M 31 revolves once in 130 million years; other periods range from 3 to over 400 million years.

The Sun shares the rotation of our own galaxy. It is about 8,000 parsecs from the galactic centre, a little beyond the radius of

NGC 1300, a typical barred spiral galaxy in *Eridanus*.
(*Mount Wilson – Palomar*)

MESSIER 64, a spiral galaxy in *Coma Berenices*, photographed with an eight-hour exposure. (*Ritchey*)

THE WHIRLPOOL GALAXY, Messier 51, in *Canes Venatici*. One of its two spiral arms reaches out towards its unusual companion.
(*Mount Wilson – Palomar*)

maximum rotational velocity. Moving at about 225 km per second (and carrying the entire solar system with it) it will complete one revolution about the galactic centre in 200 million years. Comparisons with M 31 show the Milky Way galaxy to be very similar in character, but slightly smaller and also rather less massive. (R.G.)

EYEPIECE. The **lens** system at the viewing end of a **telescope**. The eyepiece is in effect a microscope through which the image formed by the telescope objective is examined. Eyepieces, like microscopes, can have a variety of magnifying powers, and generally several are provided with one telescope to give a number of different magnifications.

The commonest form of eyepiece is named the Huyghenian, after the astronomer Huyghens; it consists of two convex lenses spaced a short distance apart. Although it is satisfactory for use with most refractors it is generally unsuitable for reflecting telescopes on account of their relatively short focal lengths.

F

F CORONA. The outer part of the Sun's corona. See **Sun**.

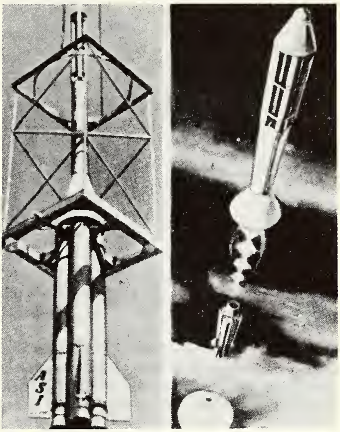
F LAYER. An ionized layer at an altitude of about 150 miles in the Earth's atmosphere. See **Ionosphere**.

FACULAE. Unusually bright patches in the solar photosphere. See **Sun**.

FALCON. An air-to-air interception **missile** of the U.S. Air Force.

FALLING SPHERE. An inflated fabric sphere used to find the density of the atmosphere at great heights. The collapsed sphere is taken in a rocket to the top of the trajectory, and then released and automatically blown up by means of a pressure bottle inside it. A small radio set in the sphere receives and re-transmits signals from a ground station which enable its rate of fall to be measured (see **Doppler Radio**). From this the air density can be derived.

FARSIDE ROCKET. In October 1957, two rockets fired as part of the U.S. research project Operation Farside reached heights estimated as 4,000 miles. The rockets were carried aloft in cages slung underneath vast balloons of the *Skyhook* type.



THE FARSIDE ROCKET. *Left:* the complete rocket in the cage by which it is held suspended under the ballon. *Right:* a drawing of the second stage soaring up while the first stage drops away. The ballon through which the rocket ascended is collapsing (*lower margin*).

The rockets were carried to about 100,000 feet and then fired, piercing the balloon and ascending through it. Each rocket weighed 1,900 lb. and consisted of a four-stage combination of ten solid-propellent rocket motors. The helium-filled balloon had a capacity of over three million cubic feet.

The name *Project Farside* has been given to a U.S. Air Force moon-rocket using a similar launching technique.

FIELD. The region over which the effects of a force such as gravity or magnetism are appreciable. At any point within it the field has a certain strength and acts in a certain direction. For instance, the field of gravitational attraction of the Earth at a point at ground level acts vertically downwards with a force corresponding to an acceleration of 32 feet per second per second.

FIELD OF VIEW. The area of the sky which is visible at any one time in a **telescope**. The term is often abbreviated to 'field'. The diameter of the field depends on the telescope and on the eyepiece employed, and is usually quoted in minutes or degrees of arc. The diameter of the photographic field of view of the 200-inch Hale telescope is about 10′ of arc; this means that one photograph covers one millionth of the visible hemisphere of the sky.

FILAMENTS, SOLAR. Dark linear markings shown on the Sun's disc by a **spectroheliograph**. See **Sun**.

FINDER. A small telescope enabling a larger one to be quickly trained on to specific objects.

A large telescope generally has a **field of view** of less than one degree of arc, and it is frequently difficult to locate an astronomical object in such an instrument. On the other hand it can be readily found in the large field of view of the finder. The latter is mounted on the large telescope and adjusted so that it points in the same direction. If a star is brought to the centre of the finder field, it will be in view in the main telescope.

FIREBALL. A very bright **meteor**.

FIREFLASH. An air-to-air interceptor **missile** for the Royal Air Force.

FIRST POINT OF ARIES and **FIRST POINT OF LIBRA.** See **Celestial Sphere.**

FLARES, SOLAR. Brilliant eruptions of light from glowing hydrogen in the solar chromosphere in the neighbourhood of sunspots. See **Sun**.

FLASH SPECTRUM. The spectrum of the solar chromosphere observed at the beginning and end of a total solar eclipse, when the layers of the Sun below the chromosphere are still hidden from view by the Moon. Its name derives from the suddenness of its appearance and its brief duration. See **Sun.**

FLYING SAUCER. Journalistic phrase that has been applied to various objects reported to have been seen in the sky by casual observers. Meteorological balloons, refraction phenomena, searchlight beams playing on clouds and Venus seen in daylight are among the commoner causes of such reports. Photographs of 'flying saucers' supposed to have landed are cool impostures.

The term has also been used as a nickname for some experimental aircraft designs. (M.T.B.)

FOCUS. See **Conic Sections**. For optical focus, see **Lens** and **Telescope.**

FORBIDDEN LINES. These lines sometimes appear in the spectra of very tenuous gases and arise from normally rare transitions between energy levels in **atoms**. They have been observed in the spectra of the uppermost parts of the Earth's atmosphere, the solar corona, and galactic nebulae. See **Spectroscopy**.

FRAUNHOFER LINES. The absorption lines in the spectrum of the Sun. The term is also used rather loosely for the absorption lines in the spectra of other stars. Fraunhofer himself catalogued over 750 lines, and over 26,000 have subsequently been recorded in the parts of the solar spectrum which have so far been accessible to observation. (See **Spectroscopy**.)

FREE FALL. The condition of unrestricted motion in a gravitational field.

On the Earth's surface the ground restricts the downward motion that would otherwise take place. In a rocket or satellite coasting without power, the rocket and all its contents are equally under the influence of **gravity**, irrespective of the distance from the Earth, and the entire rocket is in a state of free fall. It may still be moving upwards under its own momentum, but from the moment it begins to coast it is technically falling.

In these circumstances, the organs of balance in the human ears do not function,

MICE AND MEN IN FREE FALL. The two mice are in separate containers, one behind the other in a rocket after all-burnt. One container has a shelf, which the occupant holds in apparent comfort; the other mouse finds conditions rather puzzling, but neither was found to be any the worse for the trip. A ball is included in one of the containers.

The men are floating about in the cabin of a U.S.A.F. C-131 transport aircraft during zero-gravity manoeuvres. For some fifteen seconds the aeroplane is in a state of free fall, while Surgeon-General Oliver K. Niess and some Project Mercury astronauts in full-pressure suits learn to control their body movements.

and controlled muscular movements are difficult until some practice has been acquired (see **Space Medicine**). Many of the most ordinary actions become complicated or impossible: everything that is not fastened tends to float about, and liquids behave rather like balloons filled with air and drift out of open vessels at the slightest local disturbance.

Conditions inside the rocket are then *as if* there were no gravitational field acting, but this is only because there is *no difference* between the effects of gravity on the rocket, on objects inside it and on their 'supports'. (See **Gravity, Artificial.**)

In other words, free fall does not depend at all on the absence of gravity, but only on the absence of all accelerating or retarding forces other than gravity. Except for the retarding force of air resistance, a cricket ball would be in free fall from the moment it leaves the thrower's hand, even while it is still rising. An object resting on a table is not in free fall because the support of the table opposes the action of gravity.

FREQUENCY. The frequency of a wave motion is the number of cycles it completes in one second. See **Wave Motion.**

G

g. A symbol for the force of **gravity** at the Earth's surface. This force will accelerate any body in free fall by 32 feet per second per second, and this **acceleration** is equal to 1 g. This unit can be used indiscriminately to express any acceleration or gravitational force. For instance, a rocket whose speed increases by 96 feet per second every second is said to be accelerating at 3 g. For the effects of acceleration on human beings, see **Space Medicine**.

G LAYER. An ionized layer at a height of 300–400 miles in the Earth's atmosphere.

GALACTIC ABSORPTION. The absorption of light by interstellar matter in the **Galaxy**. Large particles block light of all wavelengths equally and cause an overall lowering of the intensity of the light. Small particles whose dimensions are comparable with the wavelength of light cause a reddening, as they scatter the blue end of the spectrum more than the red. This is quite different from the reddening due to the **Doppler effect**, which *displaces* the entire spectrum of a receding light source to the red and alters the positions of the spectral lines without changing their relative strengths. Absorption reduces the background brightness of the continuous spectrum more in the blue than in the red, but does not displace the lines.

Owing to the concentration of dust in the galactic plane, the reddening and absorption are most noticeable when we look along this plane from the Earth at distant objects: no extragalactic nebulae are visible near this plane, the whole of their light having been absorbed before it reaches us.

GALACTIC CLUSTER. A loose aggregation of stars occurring in a spiral galaxy (see **Extragalactic Nebulae**).

The number of stars in a galactic cluster is no more than a few hundred, and their arrangement is usually haphazard, with perhaps a slight concentration towards a centre; the contrast with **globular clusters** is very striking. Over three hundred galactic (or *open*) clusters have been found in our Galaxy, and many more in other spirals.

The galactic clusters of the **Pleiades** and the Hyades in the constellation Taurus are obvious to the unaided eye; the Double Cluster in Perseus is a splendid object in a small telescope.

Galactic clusters lie in the spiral arms of galaxies and participate in galactic rotation, and belong to Population I (see **Galaxy**).

GALACTIC NEBULAE. Clouds of interstellar matter whose presence is revealed either because they are illuminated by a bright star or because they noticeably weaken the light from stars in a particular region of the sky. The former are *bright* and the latter *dark* nebulae. Both types are found in our own and in other spiral galaxies.

The bright nebulae in the Milky Way system are usually closely associated with bright stars; a few probably derive their energy from the collision of two interstellar clouds. If the illuminating stars are very hot, their ultraviolet radiation can cause the interstellar matter to glow. An excellent example of an irregular nebula of this type is the **Orion Nebula**.

The *planetary nebulae*, an allied type, are symmetrical shells of gas round extremely hot

NGC 3587, a planetary nebula in the Great Bear constellation. The hot central star is well shown. (*Mount Wilson – Palomar*)

stars. These shells, which are similar to those thrown off during **nova** outbursts, probably originate from the central star, whereas it is likely that the hot stars in irregular bright nebulae have recently formed from the nebulae.

Some planetaries appear ring-shaped. This is an effect of perspective, the denseness of the shell appearing greatest when we look through the edge of the apparent disc and least when we look through its centre. The shell often appears of different sizes when viewed in light of different colours: the same emission lines are not all excited in the same layers.

In many parts of the sky, particularly in the Milky Way, there are dark patches where few stars are visible, e.g. the **Coal Sack**. The *dark nebulae*, relatively dense clouds of interstellar matter, obscure the light from stars in the direction of these patches. They attract more material from the surrounding space by gravitational attraction and by **radiation pressure** of starlight (which acts only *towards* the nebula owing to the latter's darkness). A nebula like the Coal Sack doubles its mass in this way in something like 100 million years. Local condensations may form within the nebulosity and become heated by the energy

THE COAL SACK and, to the right and above it, the Southern Cross.

of motion of the particles that have been attracted; as these condensations continue to contract and at the same time gain in mass by their increasing gravitation, their temperatures and densities rise and they begin to emit light. This may well be the manner in which stars are born. (R.G.)

GALAXY, THE. The spiral system of stars of which the Sun is a member.

Observation of the night sky in the absence of moonlight, even with the naked eye, leads to the conclusion that space does not seem to be uniformly populated with stars. An irregular streak of luminosity, known as the *Milky Way*, runs right across the sky. A telescope reveals that this luminous band contains myriads of stars. We live in a disc-shaped aggregation of stars, and when we look at the Milky Way we are looking along the plane of the disc and thus seeing a great thickness of star-populated space; in other directions we are looking out of the disc into the relatively empty space beyond.

Many objects which we can see in directions away from the Milky Way are far outside the disc of stars, or *Galaxy*, in which we live. They are the **extragalactic nebulae.** One of the nearest and largest of these is the **Andromeda Nebula**; and our own Galaxy is thought to be very similar to that object.

The disc-shaped extragalactic nebulae have several features in common: the discs are not uniform but consist of spiral arms, which are coiled round a nearly spherical mass called the *nucleus*. The diameter of the nucleus is considerably greater than the thickness of the disc (see the photograph of the nebula named NGC 4565 in the article on extragalactic nebulae); and photographs with the largest telescopes show the nucleus, like the spiral arms, to consist mainly of stars.

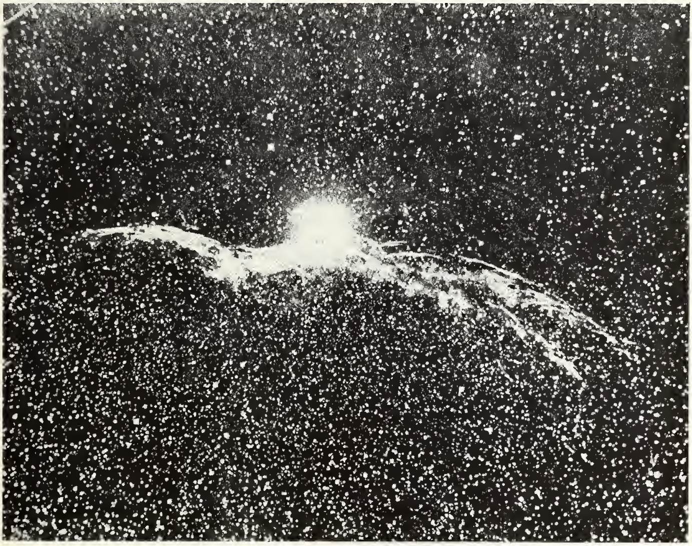
In our attempts to discover the form of our own Galaxy we are severely handicapped by being inside it: we are rather in the position of an ant trying to map a large lawn from a fixed position amongst the blades of grass composing it. An additional difficulty is that there is much dark obscuring matter in the plane of the Galaxy; this is seen also in photographs of other spiral extragalactic nebulae, or spiral galaxies, as they are called.

However, a good deal has been discovered about the form of our own Galaxy. In other galaxies, as in our own, **globular clusters** of stars are to be seen. Those of other galaxies are not confined to the plane of the disc but are distributed spherically about the nucleus. The positions of the globular clusters of our Galaxy appear strikingly asymmetrical: they are concentrated in the region of the constellations *Scorpio* and *Sagittarius*, and the galactic

Part of the MILKY WAY in Sagittarius. These dense star clouds lie in the direction of the galactic centre. (*Mount Wilson*)

nucleus must also lie in this direction. There are very heavy dark clouds of obscuring matter between us and the nucleus which prevent our seeing the centre of the Galaxy; recent photographs taken in infra-red light, which penetrates the clouds better than visible light, reveal very dense star clouds which are probably on the edge of the nucleus. The distances of the globular clusters show the nucleus to be at the great range of 8,000 parsecs from us.

that one revolution is completed in about two hundred million years, and this in turn enables us to estimate that the total mass of the Galaxy is about a hundred thousand million times that of the Sun – rather less than that of the Andromeda Nebula but well above the average. Radio observations show that the direction of rotation is such that the spiral arms trail, rather than precede the nucleus. The same conclusion has recently been reached concerning other galaxies.



FILAMENTARY NEBULA in Cygnus. *(Mount Wilson – Palomar)*

Attempts have been made to map the spiral arms of our Galaxy by measuring the directions and distances of stars.

The motions of stars, especially the bright O and B type stars which can be seen very far away, show that the Galaxy is rotating, at a velocity in our neighbourhood of about 200 kilometres per second, with a circular motion about the nucleus. Knowing the distance of the nucleus, we may calculate

The picture of our Galaxy so far given is one that we, with our greatly biased view from far out in one of the spiral arms, might easily think to be the complete one; but the true picture is more complicated. We have already seen that the globular star clusters do not lie in the plane of the disc: their radial velocities show that they do not take part in the general rotation of the galaxy. They must, owing to the gravitational force acting on

NEBULOSITIES IN MONOCEROS, part of the Milky Way. Above is a small section of a 48-inch Schmidt plate, with the curious Cone Nebula at the centre. Below is a 200-inch photograph of the Cone Nebula. A wedge of dark obscuring matter is seen with a bright star at its apex.

them, revolve about the galactic centre, but they move in orbits more or less steeply inclined to the plane of the galaxy. RR Lyrae **variable stars** also move in such orbits. Quite a number of stars even in the solar neighbourhood have velocities relative to the Sun which are far above the average and such stars are often moving in a direction which will soon carry them out of the galactic plane: thus they, too, have inclined orbits.

Two quite distinct star populations may therefore be distinguished in our Galaxy; these have been named *Population I*, which includes the objects of the spiral arms that show a marked concentration towards the galactic plane, and *Population II*, which is composed of stars ranged as a more or less spherical halo about the nucleus. This is probably typical of all spiral galaxies; photographs of some of these show clearly the Population II halo.

The **Hertzsprung-Russell diagram** shows that the two populations must have very different histories, and enables us to say that the stars of the nuclei of other galaxies (and hence, in all probability, our own) are Population II objects.

Population I seems everywhere to be connected with interstellar dust clouds. The very bright O and B stars are using up their hydrogen at such a prodigal rate that their lifetime cannot be more than 20 million years. Possibly they have formed from interstellar dust at very recent dates. Population II, on the other hand, contains no dust, and galaxies such as elliptical galaxies (described under extragalactic nebulae) which contain only Population II stars are completely free from dust and obscuration. Faint galaxies may be seen shining through them. Population II stars cannot now be forming, therefore, and are probably older than those of Population I. (R.G.)

GALVANOMETER. An instrument for measuring weak electric currents.

GAMMA-RAY. A very high-energy **photon**. Gamma rays are electromagnetic waves of the shortest known wavelength, from 10^{-11} to below 10^{-14} cm. They are produced by the disintegration of the nuclei of atoms such as radium.

GANTRY. A metal framework housing a

ATLAS 12B IN FRONT OF ITS GANTRY.

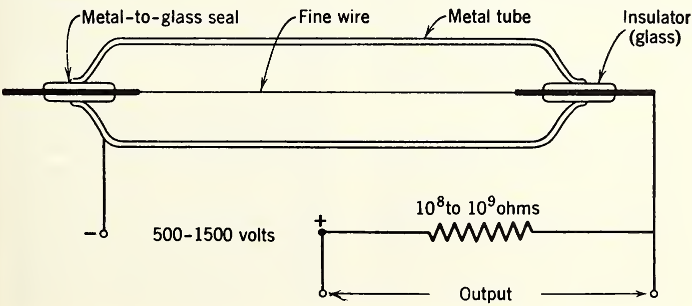
vertical missile prior to launching. It provides shelter for the missile, and contains platforms at different levels for testing and servicing. When the missile is about to be launched the gantry is rolled aside.

GANYMEDE. The brightest and most massive of the satellites of Jupiter, though in size it seems to be slightly inferior to Callisto. The diameter is 3,200 miles, and the mass over twice that of the Moon. As it has an escape velocity of 1.8 miles per second, Ganymede might be expected to retain a tenuous atmosphere; but so far none has been detected. Surface details can be observed with large instruments. (See **Jupiter.**)

GEGENSCHEIN (*lit.* 'counter-glow'). See **Zodiacal Light.**

GEIGER-MUELLER COUNTER. An instrument for detecting charged particles and high-energy radiation, e.g. γ-rays.

The basic parts are a metal tube, filled with gas at low pressure, and a metal wire which runs through the centre of the tube. A fairly high voltage is applied to the wire and the tube, which are insulated from each other. When a fast particle or a γ-ray enters the tube, **ions** are formed by its violent collisions with atoms of the gas. But virtue of their charge, the ions are attached to the wire or tube, and their collisions with other atoms *en route* furnish more ions. The resulting stream of charged ions is equivalent to the flow of a small current whose existence betrays the entry into the tube of the original particle or ray. The current is sufficient to give a loud click in a telephone receiver connected in the circuit, or it may be amplified to operate a recorder or counting mechanism. Many modifications of the tube counter have been evolved for specialized purposes. In particular, it can be screened so that only particles from a certain direction are registered, and two or more counters can be placed one behind the other to time the speed of a particle which traverses them all in turn.



GEMINIDS. One of the richest of **meteor** showers, with maximum activity about December 12.

GEODESY concerns itself with the study of the **Earth's** dimensions, elasticity, mass and local variations of gravity.

GEOGRAPHIC POLE. One of the two points where the Earth's axis of rotation cuts its surface. All geographic **meridians** meet at the poles. Since the **magnetic poles** are at a considerable distance from the geographic poles, compass needles do not as a rule point exactly towards the geographic poles.

The Earth's axis of rotation differs slightly from its axis of symmetry. The difference causes a wandering of the precise location of the geographic poles in cycles of 432 days, over a range of about 60 feet, and hence corresponding small changes in latitudes all over the Earth.

A far more gradual and sustained change arises from the movement of the Earth's crust relative to the axis of rotation. (During the last 150 million years both England and North America have moved from near the equator to their present positions, but are almost stationary now.) The motion of land masses in relation to the poles has been called *polar wandering*, although that expression is putting the cart before the horse.

GIACOBINIDS. An alternative name for the **October Draconid** meteor shower.

GIANT STARS. These are stars whose diameters are considerably greater than those of most stars of similar surface temperature in the neighbourhood of the Sun. (See **Hertzsprung-Russell Diagram.**)

GIBBOUS (of Moon or planet). The phase when more than half the disc appears illuminated, i.e. between 'half Moon' and 'full Moon'.

GLOBULAR CLUSTER. A dense, spherically symmetrical aggregation of stars. Globular clusters occur in our own Galaxy and have been discovered in nearby spirals (see **Extragalactic Nebulae**). Two globular clusters of our Galaxy are visible to the naked eye: they are ω Centauri and 47 Tucanae, both in the southern sky. Many others can be seen in small telescopes, but an instrument with an aperture of at least ten inches is required to show a cluster well resolved into separate stars.

A GLOBULAR CLUSTER, Messier 3 in the constellation Canes Venatici. (*Ritchey*)

The **Andromeda Nebula**, which is very similar to our own Galaxy, has about two hundred known globular clusters distributed roughly spherically around the nucleus. Over a hundred clusters are known in our Galaxy; they appear mainly in the direction of the constellations Scorpio and Sagittarius, and, assuming that these too have a spherical distribution, they indicate that the centre of the galaxy lies in that vicinity. The globular clusters do not take part in the rotation of the galaxy as a whole, but move in eccentric orbits at high inclinations to the galactic plane.

The number of stars in a globular cluster is difficult to estimate, as only the brighter ones can be seen; even the most laborious work with the world's largest telescope, the 200-inch on Mount Palomar, has not made it possible to discern in a cluster individual stars less bright than absolute magnitude 6. A conservative estimate places the total number in a cluster at a hundred thousand. The distances of many globular clusters have been found by examining the RR Lyrae variables contained in them (see **Variable**

Stars). These measurements enable us to say that the distance of the centre of the galaxy is about 8,000 parsecs, and show that the absolute magnitudes of whole clusters range from -5 to -10.

Recently, great interest has been taken in the stellar population of globular clusters. The brightest stars are red, instead of blue as is the case for stars near the Sun. The work on this subject is described in the article on the **Hertzsprung-Russell Diagram**, which also shows the curious relationship of the RR Lyrae stars in a cluster to the cluster as a whole. (R.G.)

G.M.T. Abbreviation for **Greenwich Mean Time**.

GRAVITATION. The force which exists between all particles of matter everywhere in the Universe. The force is one of attraction, and between any pair of bodies it is proportional to the mass of each and inversely proportional to the square of the distance between them.

(Thus by doubling the distance separating two bodies, their mutual attraction is reduced to one quarter its original value; by doubling the mass of one body and trebling that of the other, the gravitational force between them is made $2 \times 3 = 6$ times as great as before.)

The gravitational field of a body extends throughout the universe. It becomes rapidly weaker and finally negligible with increasing distance, but never quite ceases. It is therefore wrong to suggest that any place, however far away, is beyond the Earth's gravity, although outside a certain range the gravitation due to some other body may greatly exceed that due to the Earth. (See also **Free Fall**.)

There is a fundamental difference between *mass* and *weight*. The mass of a body is the amount of matter in it, regardless of where the body is placed. Weight is the force of gravity exerted on a body, and depends not only on mass but also on the strength of the gravitational field at the place where we measure the weight. Confusion sometimes arises because the same units are employed to express both weight and mass: the mass of a body is equal to its weight *at the surface of the Earth*. Thus, on the Earth, a cubic centimetre of water has a mass of 1 gram and weighs 1 gram; on the Moon, the water still has a mass of 1 gram, but its weight is only 1/6th of a gram, because the Moon's gravitational attraction is 1/6th of that of the Earth.

If a body in a gravitational field is free to move it will fall, i.e. it will be accelerated. We can state the strength of a gravitational attraction in terms of the acceleration it imparts to a freely falling body (see **Acceleration**).

The nature of gravitation is still a mystery. Certainly there can be no question of 'shielding' against it by means of screens as we can in the case of radiation.

GRAVITATIONAL LOSS. The loss of efficiency of a rocket escaping from the Earth occasioned by the time required for **escape velocity** to be reached. If the rocket could attain escape velocity instantly, it would require not more than the theoretical minimum of energy to escape. But an actual rocket cannot do this; it is limited by the power of its motors. For each second that the rocket spends in accelerating, the gravitational attraction of the Earth retards it by about 32 feet per second (roughly 20 m.p.h.). Even if the period of acceleration were as short as 100 seconds (corresponding to an improbably great average acceleration of over 10 g) it would involve a loss of $20 \times 100 = 2{,}000$ m.p.h., which is not negligible even in comparison with the Earth's escape velocity.

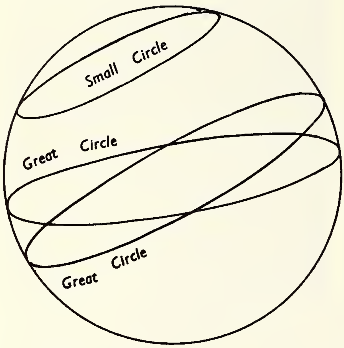
A simple analogy may be drawn with a man running *up* an escalator which is moving *down* with constant speed. If he ran so fast that he got to the top instantaneously, he would have climbed no more steps than if he had gone up a flight of stairs of similar height; but the longer he spends on the escalator the more steps he will have had to climb before reaching the top.

GRAVITY, ARTIFICIAL. The centrifugal force which may be used to simulate gravity in manned rockets and space stations.

Long periods of **free-fall** conditions may have harmful effects on the human system and will certainly be a considerable inconvenience. If the inhabited spaces are rotated about a suitable axis, the resulting centrifugal force will be in all respects equivalent to a gravitational field directed outwards from the axis of rotation. The strength of this field at any point increases in proportion to that point's distance from the axis of rotation, and to

the rate of spin. Some rather ambitious designs for **space stations** envisage the living accommodation disposed in a ring round the axis of the station. For a station with a diameter of 256 feet, one revolution in three seconds would furnish gravitation equal to that at the Earth's surface.

GREAT CIRCLE. A circle on the surface of a sphere which has the same centre as the sphere. The shortest route across the surface of a sphere between two points on it lies along the Great Circle through those points.



The term is applied to the Earth as though it were a perfect sphere. The equator is a Great Circle, and each **meridian** of longitude is half a Great Circle. By contrast, parallels of latitude other than the equator are *Small Circles.*

GREENWICH MEAN TIME is the time at Greenwich according to the **Mean Sun**, and is a standard to which all observations can be referred.

GREENWICH MERIDIAN. The line of longitude which bisects the now obsolete Airy **transit circle** of the **Royal Greenwich Observatory**. This line is used as the arbitrary zero of longitude measurements on the Earth's surface, and all other longitudes are reckoned in degrees East or West from it.

GREGORIAN CALENDAR. The calendar now in use. See **Julian Calendar.**

THE GREAT BEAR (*Ursa Major*), also known as The Plough or Big Dipper. From the left, the stars are Benetnasch, Mizar with the faint Alcor ('The Test') close by, Alioz, Megrez, Phecda and the two Pointers, Merak and Dubhe; about five times the distance between the Pointers along the line joining them lies the Pole Star.

GUIDED MISSILE. A self-propelled bomb whose path can be controlled from within or without.

A great deal of recent progress in rocket technology stems directly from the urgent need to develop efficient guided missiles. Many of the problems of rocket flight are common to its military and scientific applications, and a number of guided weapons have been adapted to serve as research vehicles.

At the conclusion of the Second World War several governments gave priority to the development of guided weapon defensive systems in which electronic devices are linked to supersonic missiles.

The first guided missiles were accordingly weapons designed to augment the existing fighter aircraft defences and they were, indeed, logical developments from the unguided air-launched rockets which had proved so effective during the final phase of the war. Electronic fire control and guidance systems were perfected to bring the fighter aircraft within range of the attacking bomber, when the guided missile is launched from the aircraft automatically. Within the missile electronic devices then ensure that it proceeds

THE FALCON air-to-air guided missile scoring a direct hit on a target aeroplane. The smoke trail marks the path it followed.

towards the target, allows for any evasive manoeuvres, and explodes its warhead within lethal distance. Such a missile is known as an air-to-air missile.

A more modern defensive system relies upon a long range surface-to-air missile to replace the fighter aircraft and to carry the air-to-air missiles to within range of the attacking bomber. An example of a system of this nature is the Boeing BOMARC used in conjunction with the Hughes FALCON. The Bomarc is a large winged missile powered by a liquid-propellent rocket booster followed by sustained propulsion at supersonic speed by two Marquardt ramjets. It is launched from the ground and guided electronically to the target. Carried within the Bomarc are a number of Falcon air-to-air missiles which are discharged automatically at the correct range from the target. When they have been discharged the large expensive missile can return towards its base and be recovered for use again. This system reduces the cost of guided missile defence by ensuring that the long-range surface-to-air vehicle is not destroyed when interception takes place.

The ever-increasing speed of bomber aircraft made this type of missile defence essential. Interception by manned aircraft becomes quite impossible because the time factor demands excessive accelerations which human pilots could not withstand. Moreover it takes more time for a piloted aircraft to become airborne than it does for a long-range surface-to-air missile. Radar warning of an impending attack may only be given when the attacking bombers are within half-an-hour of the target, and the time and speed requirements are such that the interceptor can only be certain of one chance of interception. If the bomber is not destroyed, then the interceptor does not have a second chance. As even missiles cannot be certain of a kill, guided weapon defensive systems rely upon an inner ring of short-range surface-to-air missile-launching sites surrounding each vital target area. Missiles of this nature have ranges of 20 to 40 miles and can be regarded as last-ditch defences which can prevent the nuclear explosion from taking place over the target but cannot destroy the attacker far enough away to avoid the dangers of radioactive fall-out.

Examples of short-range missiles include the Douglas NIKE and the Convair TERRIER. The Nike is a liquid-propellent rocket with a solid-propellent take-off booster. It is stored in underground magazines and fired from a short launching device when radar detectors identify enemy aircraft crossing the perimeter of the defence area covered by the Nike battery. The missile travels at supersonic speed guided by a radar beam from the ground and a homing device within the missile itself. It seeks out the target and explodes its warhead when within lethal distance.

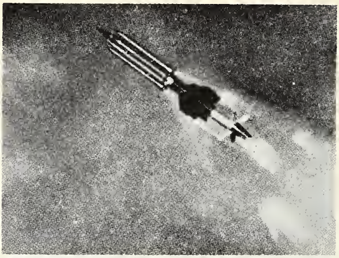
The Terrier is a similar type of weapon which uses solid-propellent rockets for both booster and missile. It can be launched from ships or from shore installations.

As these defensive missiles have moved from experimental versions into production the military art has called upon missile technologists to produce other vehicles which

stand a better chance of carrying nuclear weapons to a target even if that target has a guided weapon defensive screen around it.

The first use of missiles for offensive work is to produce an air-to-surface vehicle. The idea is to make it possible for the bomber to carry a nuclear-warhead missile over trans-continental ranges, but not to attempt an approach close enough to the target for its defences to be able to engage the expensive bomber. At over 100 miles from the target the bomber will release its missile which can accelerate to supersonic speeds and climb high into the stratosphere guided by radio from the mother plane or from special high-speed guidance aircraft sent out with the bomber. At the correct range the missile will start to dive on to the target at a very high speed, so that it will become immune to interception by surface-to-air guided weapons.

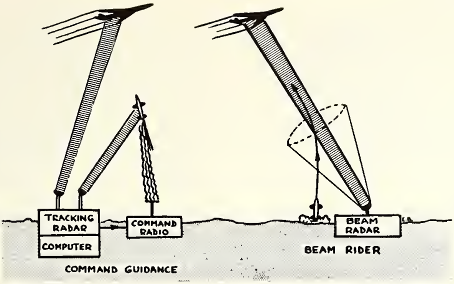
The next logical outcome of guided weapon development is the elimination of piloted bombing aircraft, in the same way that manned fighters are being replaced by guided weapons such as the North American



Left: An early British guided missile. A ring of boosters surrounds the main projectile.
Above: The booster rockets dropping off a modified version of the same missile while the main propulsion unit takes over.
(*Ministry of Supply*)

NAVAHO; the Northrop SNARK and the Convair ATLAS. They are all strategic inter-continental weapons carrying nuclear war-heads. The Navaho is a swept-wing aircraft powered by ramjets, and flies high in the stratosphere at a speed of perhaps four times that of sound. The Snark is a swept-wing turbo-jet missile which only reaches subsonic speeds, while the Atlas is a multi-stage rocket vehicle which descends on the target from a height of 800 miles and at a speed of over 10,000 miles an hour. It is an intercontinental ballistic missile which will present an almost insoluble problem of interception.

Much ingenuity has been expended on making guidance equipment light and reliable. It must continue to function even if a few components should fail.



As far as defensive missiles are concerned guidance systems fall into two main types. The simplest arrangement is known as *Command Guidance*. This system relies upon two radars, one for tracking the target and the other for tracking the missile. The outputs from these trackers are fed into a computer which determines the commands which have to be transmitted by the command radio link in order to cause the missile to intercept the target. The airborne equipment is accordingly minimized and it consists of a receiver, a decoder, and servo-mechanisms capable of changing the electrical impulses into controlling mechanical forces.

A more elaborate system is that of the *Beam Rider*. The system consists of two beams, a *wide-angle* short-range beam which gathers the missile after launching and brings it into a *tight* beam leading to the target. In addition to the servo-mechanisms, decoder and receiver of the simpler system, the missile must also carry beam-sensing devices linked to its servo system to make it fly along the axis of the beam.

These two systems are inaccurate over long ranges, and nowadays some type of homing device is added. The missile can then use the ground-based equipment to bring it fairly close to its target and rely upon its own homing device to control its final approach on to the target.

There are several different types of homing systems. *Passive* homing uses radiation from the target, such as noise or heat from the engine. The missile contains a sensing device which can detect these radiations, and a small computer issues instructions through servo-mechanisms for the missile to intercept the target. The range is fairly limited, and bombers can carry devices which confuse the missile's electronics.

Semi-active homing relies upon radiation reflected from the target and generated in the first place by a powerful radar transmitter which 'illuminates' the target from an aircraft or the ground.

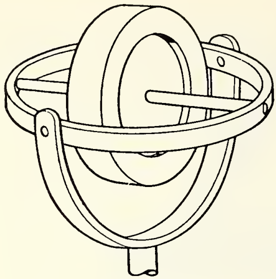
If the missile carries the illuminating radar the system is known as *active* homing. Although such a system is complex electronically it has the great advantage that as the missile approaches closer to the target the echoes increase in intensity and homing accuracy is increased.

Stand-off bombs are guided missiles released from a carrier plane at some relatively safe distance from a ground target, to which they then proceed at high speed under various forms of guidance.

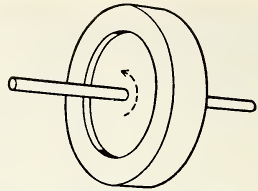
Surface-to-surface missiles which are used over much longer ranges need more advanced systems of guidance. Accuracies of 1 mile in 5,000 are necessary; a possible way of achieving this is described under **Inertial Guidance**.

The progress of a missile can be checked by reference to a radar grid or else by means of a star-tracking device which ascertains the exact position of the missile by optical observations of certain stars. This form of celestial navigation is proof against enemy interference.

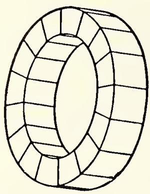
At the time most missile programmes started, the basic aerodynamic facts concerning flight at high speeds were unknown, and supersonic wind tunnels did not exist. Early missile development therefore relied upon



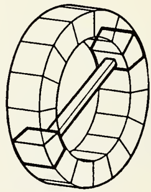
1. The Gyroscope.



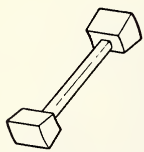
2. The Wheel is rotating rapidly, in an upright position.



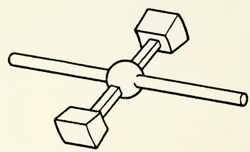
3. Suppose the rim is split into segments.



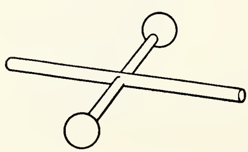
4. Attend to two of these segments.



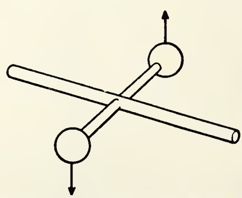
5. Forget all the other



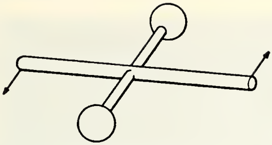
6. These segments are rigidly connected to the axle.



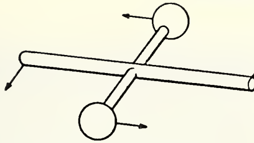
7. Their shape does not matter.



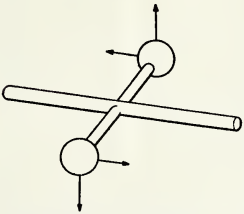
8. As the segments turn about the axle one moves up and the other down.



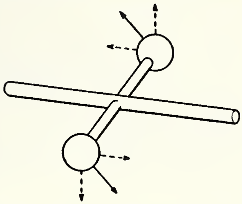
9. Now suppose we give the axle a horizontal twist.



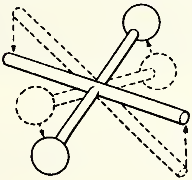
10. This gives the segments a push, one to the right, the other to the left.



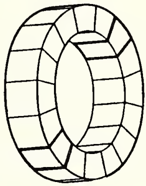
11. Thus the segments now have both a horizontal and a vertical motion.



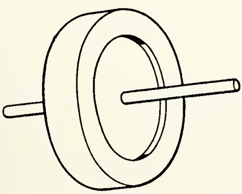
12. They therefore move diagonally.



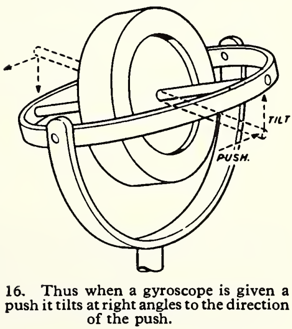
13. This is the key diagram. Study it carefully. The axle is rigidly connected to the segments and must therefore tilt when the segments move diagonally.



14. All the other segments must tilt in the same way.



15. Therefore the whole wheel tilts.



16. Thus when a gyroscope is given a push it tilts at right angles to the direction of the push.

From Professor G. P. Meredith's article on Visual Education.

test vehicles, but experiments with these are expensive and time-consuming. Nowadays computing machines are used to solve missile problems without firing actual rockets. (E.B.)

GYRO-COMPASS. See **Gyroscope.**

GYROSCOPE. A heavy wheel or disc which can be made to spin. Its axle is supported by a system of concentric rings or *gimbals* in such a way that the outer ring may be tilted or turned without moving the wheel with it. Any spinning body tends to keep its axis of rotation pointing in the same direction in space. Once a gyroscope is set in rotation its axle will therefore maintain a constant direction, and since it is mounted in gimbals it is able to do so even while the Earth is turning under it; in the course of one day the axle *appears* to sweep out the surface of a cone within the gimbals, but it is the gimbals that are in fact turning with the ground about the axle.

A gyroscope can be kept running for long periods by electrical means without its freedom to move within the gimbals being hindered. It can be started with the axle pointing due North, and it will then continue to point towards the North. A gyroscope may thus be used as a compass, when it is called a *gyro-compass*. Once properly aligned it indicates true geographic North, and not magnetic North. It is unaffected by nearby masses of iron or electrical machinery. A large gyroscope can stabilize the motion of a ship in a seaway, and stop a rocket or space vehicle from 'tumbling'. (See diagram on previous page.)

H

HALLEY'S COMET. This, perhaps the most famous of all the **comets**, was also the first whose return was predicted. Edmond Halley, observing it in 1680 and applying Newton's new laws of gravitation, computed its orbit and identified it with the great comets of 1607 and 1531. He did not live to see its return in 1758, within a few weeks of the time he had predicted.

HALLEY'S COMET AND VENUS during the comet's last appearance in 1910. The star images are elongated because the telescope followed the comet during exposure. A series of further photographs of Halley's Comet will be found in the article on comets. *(Slipher)*

Appearances of Halley's comet have been traced back in historical records to 240 B.C. The average period is 77 years, but **perturbations** by the outer planets may cause this to vary by 20 years. It passed through **aphelion** in 1948 and is now moving towards the Sun again. Its next return will be in 1986.

In 1910 its 37-million-mile tail extended more than half-way across the sky as a faintly luminous band not unlike the Milky Way. On May 21 the Earth actually passed through part of this tail, but no effects whatsoever could be observed, and even large telescopes were unable to detect distinct bodies in either the tail or the head of the comet, nor was there a measurable diminution in the brightness of the Sun or any chemical change in the atmosphere.

For details of the orbit, see under **Comet.**

HALO. Name given to optical effects sometimes seen near the Sun or the Moon, due to the refraction and reflection of their light by minute particles of ice suspended in the air. These particles tend to assume the same attitude while falling, so that the planes of the ice crystals are parallel to each other and affect the light that strikes them in a systematic manner. The result may take several forms: coloured discs of light called *parhelia* or 'sun dogs' may appear on either side of the Sun and 22° away from it, joined by a ring of light, the halo; there may be a fainter, outer ring, and the parhelia may be absent. Haloes occur mostly in high altitudes, but lunar haloes are not uncommon generally on clear, frosty nights. Parhelia have started more than one 'flying saucer' report.

HARVEST MOON. The rising of the Moon is delayed from day to day by an average of 52 minutes, but this delay varies somewhat throughout the year. It is as little as 13 minutes near the time of the autumnal equinox (in northern latitudes). For several nights the full or nearly full Moon then rises at approximately the same time early in the evening, and is called the Harvest Moon.

HAYFORD SPHEROID. The solid figure whose proportions are the same as those of the Earth. It is a slightly flattened sphere, but the flattening amounts to less than 0.5% of the diameter, and would not be detected by the naked eye in a scale model. The Earth's diameter is 7,927 miles at the equator and 7,900 miles from pole to pole. The equatorial bulge is due to centrifugal force, and is far more noticeable in the case of Saturn and Jupiter. It fluctuates in size to a minute extent under the influence of tidal forces set up in the Earth's interior by the Sun and Moon. Recent modifications are described under **Earth.**

HEAT is the energy of the random motions of molecules in a substance. The amount of heat contained in a body depends upon its temperature, and upon its specific heat. *Radiant* heat is **electromagnetic radiation** at wavelengths between those of infra-red and the shortest radio waves.

Heat can be transferred from one body to another in one or all of three ways:

A machine which tests the strength of metals at high temperatures. It can heat a rod of metal to 1,000° C. by putting a current of 20,000 amperes across it. Two powerful jaws are pulling at the specimen to determine its breaking stress. (*Lockheed Aircraft Co.*)

1. By *conduction* across the area of contact between the two bodies;
2. By *convection*, in which heat is first given up to a fluid which then moves and conveys the heat to another place – the cooling of a car engine by the circulation of water is an example of convection;
3. By *radiation*, which can take place through a vacuum. The Sun heats the Earth's surface by radiation.

When two bodies are in contact and neither adds heat to the other, then both are at the same temperature. (See also **Specific Heat, Temperature**, and **Absolute Zero.**)

HEAVISIDE LAYER. A region of the **ionosphere.** Heaviside inferred its existence from the propagation of radio waves round the Earth.

HECTOR. An asteroid of the **Trojan** group.

HELIUM. An inert chemical element. The usual form of the helium **atom** consists of a nucleus of two protons and two neutrons, with two electrons outside it. The electrons

are very tightly bound to the nucleus, and the atom is correspondingly difficult to ionize: it therefore forms no chemical compounds, and the spectral lines of ionized helium are only seen in the spectra of the very hottest stars, at temperatures far above those required to ionize most other elements. The abundance of helium in the universe is second only to that of hydrogen, and the processes of energy generation in stars involve formation of helium from hydrogen (See **Stellar Energy**.)

Helium was discovered as a constituent of the Sun before it was found on Earth. A bright yellow line was observed in the Sun's **flash spectrum** in 1868 by the astronomers Lockyer and Janssen; the line was not given by any substance known at that time. It was named helium from the Greek *helios*, meaning Sun. In 1895 a substance which gave the helium spectrum was found to be evolved on heating the rare mineral cleveite; subsequently it was detected in many mineral springs, and in natural gas.

Helium is a gas with about four times the density of hydrogen but a quarter that of air; it remains gaseous at atmospheric pressure down to a temperature hardly five degrees above absolute zero. It is produced by the radioactive decay of atoms such as radium. Owing to its low density the random motion of its atoms is rapid; helium can slowly escape from the Earth's atmosphere, as a small proportion of the helium atoms in the upper atmosphere have velocities in excess of the **escape velocity** of the Earth.

HERMES. An **asteroid**, only about a mile across, which passed within half a million miles of the Earth in 1937 and has not been seen since. No other asteroid has ever been so close, but an even nearer approach by Hermes is possible.

HERTZSPRUNG-RUSSELL DIAGRAM. Named after its inventors, this diagram is a graph on which the absolute **magnitudes** of stars are plotted against their spectral types. It is of fundamental importance in modern astronomy.

In order to know the absolute magnitude it is usually necessary to find the distance. (This is not true of all stars, for instance Cepheid variable stars have known magnitudes; so do a few other particular types of stars, but the statement remains true for the vast majority.) As the only measured distances, in the days of Hertzsprung and Russell, were those which were susceptible of measurement by **parallax**, and therefore small as astronomical distances go, it was natural that the stars represented on the diagram should be those relatively close to the Sun. Also, attempts to measure parallax had been largely confined to those stars which were likely to be near, that is, the bright stars. Relatively faint stars close at hand were not measured. Thus the effects of observational selection were enormous – all the stars on the diagram were near the Sun, and bright stars were grotesquely over-represented.

The diagram, shown schematically in Figure 1, reveals striking regularities in the properties of stars near the Sun. Most of these stars are represented by points which lie on a narrow band diagonally across the graph, indicated by the broken black line, while those which do not give points on this line are nevertheless confined, with very few exceptions, to quite distinct areas on the graph. The line representing the majority of stars is known as the *Main Sequence*. Those stars which lie above this line are brighter than main sequence stars of the same spectral class and hence of similar temperature. In order to give more light at the same temperature they must have considerably greater surface areas and are therefore called *giants*. Stars lying very far above the main sequence are *supergiants*, while those only slightly above are called *subgiants*. Similarly, those stars which are below the main sequence are called *dwarfs*, while a number of stars only just below it are *subdwarfs*. The physical characteristics of typical stars in these different categories are given in the figures below. The methods available for obtaining these data are described under the heading **Star**.

The white dwarfs show very considerable variation in characteristics amongst themselves. Although their masses are comparable with normal stars, they are of far smaller size, some being smaller than the Earth. They consist of degenerate matter of inconceivably high density, from 10,000 times that of water upwards. The densest star yet discovered is 36,000,000 times as dense as water. The gravitational fields at the surfaces of white dwarfs are many thousands of times that at

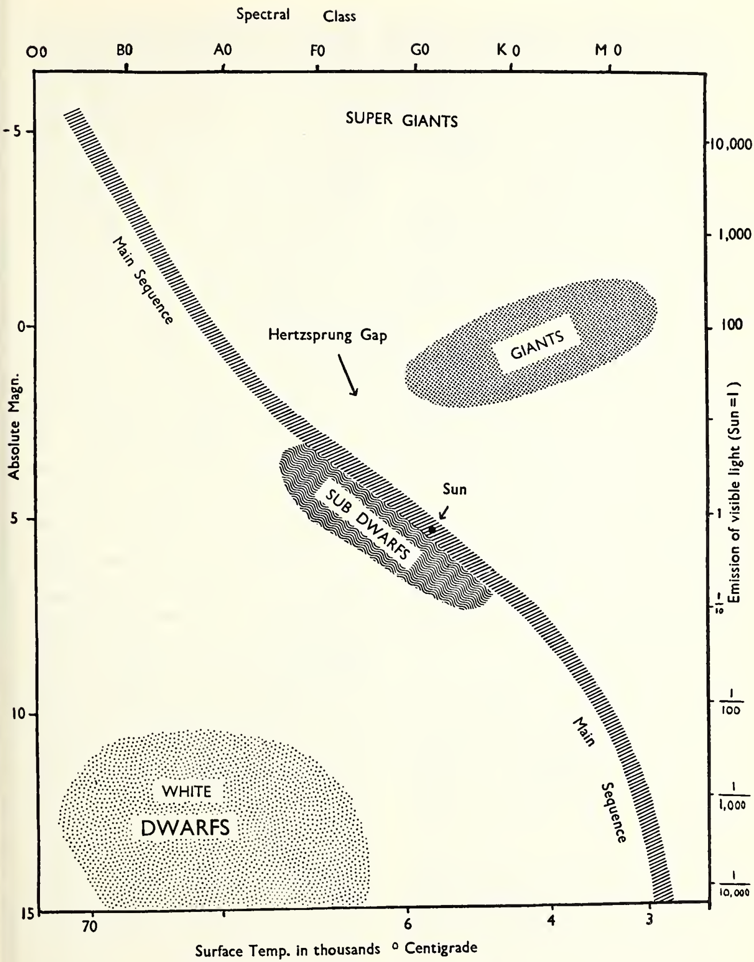


Fig. 1.

THE HERTZSPRUNG–RUSSELL DIAGRAM. The temperature scale applies only to main sequence stars. The position of a star on the diagram is found from its absolute magnitude and spectral type.

the Earth's surface, and cause the stars' atmospheres to be compressed to a total height of only a few feet. The spectra of these stars vary from O to F, so their surface temperatures are quite, and in some cases extremely, high. The white dwarfs have no source of nuclear energy, and maintain their surface temperatures by contracting: this process enables them to derive energy from their own gravitational fields.

Despite much speculation, it has not yet been possible to draw any valid conclusion from the Hertzsprung-Russell diagram regarding the evolution of stars. It was once thought that as stars grew older they became cooler and fainter and 'slid down the main sequence', but it is now found that this would not take place.

During the last decade our knowledge has been greatly increased by the observation of stars in **globular clusters.** These clusters are near enough for fairly faint stars in them to be examined, and have the advantage that all the stars are at virtually the same distance from us. We have, therefore, only to measure the apparent magnitudes and spectral types of the stars in globular clusters, draw the Hertzsprung-Russell diagram and correct all magnitudes by the same amount, the *distance modulus*. This is done by observing the RR Lyrae stars (described under **variable stars**). The RR Lyrae stars may be regarded as pathological cases – they are unstable and undergo periodic variations of light in periods of less than a day, and all have the same absolute magnitude of zero.

The Hertzsprung-Russell diagram for one of the globular clusters is shown in detail in Figure 2. There is a tendency today to use **colour index** instead of spectral class: the two are closely related, and the colour index is far more readily determined. A diagram using colour indices is often referred to as a colour-magnitude diagram, but it is fundamentally the same thing as the Hertzsprung-Russell diagram.

It is at once evident that the star population of the globular cluster is completely different from that of the neighbourhood of the Sun. Figure 3 shows the colour-magnitude diagram of the same cluster, M3, drawn with lines representing the main groupings of stars shown in Figure 2, superimposed on the diagram for stars near the Sun. The shape of the latter is slightly different from the shape in Figure 1 owing to the use of colour indices instead of spectral types. The only parts of the graphs showing any agreement are those below about the fourth absolute magnitude: here the M3 stars lie nearly on the Main Sequence. Stars below the sixth magnitude doubtless exist in M3, but were not bright enough to observe – Figure 2 shows that even these were fainter than the 21st apparent magnitude. Above absolute magnitude 4, there are two sudden corners in the diagram and the line rises and turns towards the side of increasing colour index, i.e. the brighter stars are redder. The brightest are red stars of absolute magnitude —3, in striking contrast to the brightest main sequence stars which are blue and two or three magnitudes brighter. The nearly horizontal branch of the colour-magnitude diagram shows that the blue stars in M3 are uncommon and relatively faint. A gap occurs in the horizontal branch at zero absolute magnitude: it is found that all the RR Lyrae variable stars (which are omitted in the diagram) fall exactly in this gap, and none outside, while no stars other than these variables occur in the gap. Evidently some cause of instability exists which affects all stars of the particular colour range and magnitude which correspond to the gap.

Other globular clusters have been studied, especially those designated M92 and M13; in the case of M13, observations with the largest telescope in the world were pushed beyond the twenty-third apparent magnitude in order to extend the colour-magnitude diagram as far as possible. A diagram allowing comparison between the results for M92 and M13 and for M3 is given in Figure 4. It will be seen that the three diagrams are broadly similar, but certain differences are apparent. Chief among these is the discrepancy in positions of the lower or main sequence parts of the curves. This seems certainly greater than can be explained in terms of observational errors.

The Hertzsprung-Russell (or colour-magnitude) diagrams show that there are two fundamentally different types of stellar population: one, called *Population I*, occurs near the sun, and another, *Population II*, in the globular clusters. Observations of our own and neighbouring galaxies confirms this sharp division (see **Galaxy**). Population I stars, which include Cepheid variable stars and supergiants, are found to be intimately associated with interstellar dust and occur

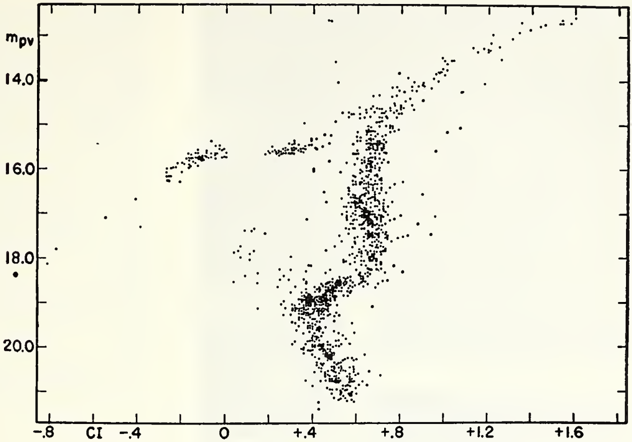


Fig. 2.

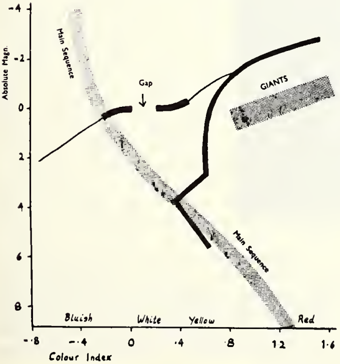


Fig. 3.

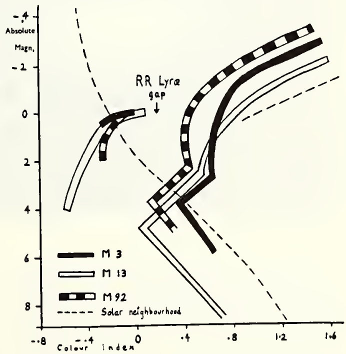
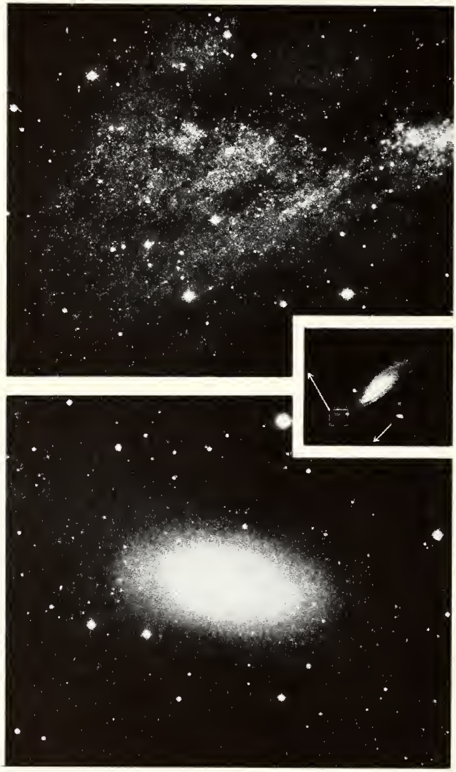


Fig. 4.

For explanations please see text.



STELLAR POPULATIONS I and II. *Top:* the Andromeda galaxy, photographed in blue light, shows giant and super-giant stars of Population I in the spiral arms. The hazy patch on the right is composed of unresolved Population II stars. *Bottom:* NGC 205, Andromeda's companion galaxy, photographed in yellow light, shows stars of Population II. The brightest stars are red and 100 times fainter than the blue giants of Population I. — The very bright individual stars scattered over both pictures are foreground stars belonging in our own Milky Way system.

(*Mount Wilson – Palomar*)

in the spiral arms of extragalactic nebulae. Population II stars form not only globular clusters but also the nuclei of spiral galaxies and occur in regions free from interstellar dust. They constitute, in addition, the nearly spherical cloud of stars which surrounds the nucleus of such a galaxy and which, like the globular clusters, does not take part in the general galactic rotation. Most of the stars in a spiral galaxy are concentrated in the nucleus, so Population II stars are more common than Population I, in a ratio of the order of 10 to 1.

Population I stars are considered to be younger than Population II, and may well still be forming from the interstellar dust among them; Population II cannot now be forming as there is no such dust in their vicinity.

The evolutionary sequence of Population I stars remains a mystery; a particularly puzzling feature is the almost complete absence of stars between the main sequence and the giant band (the 'Hertzsprung Gap') of the

Hertzsprung-Russell diagram. A start has, however, been made in interpreting the diagram for Population II stars.

The theory suggests that at some time in the distant past, when Population II stars were young, they formed a sequence similar to the present Main Sequence of Population I. The energy source of stars, at least main-sequence stars, is the conversion of hydrogen to helium in a small convective core; when the hydrogen there is exhausted the energy is generated in a shell round the core by the same process. However, when the core, thus added to, reaches a limiting mass of perhaps one-eighth of the mass of the star, this process cannot continue and some new process occurs. The indications are that this would cause the star to leave the Main Sequence and evolve in the way shown on the globular cluster diagrams above magnitude 4. Beyond this point the matter is largely speculative: for some reason not yet understood the star must evolve quite quickly to a red giant. It then returns across the Main Sequence, passing through an unstable stage as an RR Lyrae variable, to sink into obscurity as a bluish dwarf star perhaps obtaining energy by transmutation of helium to heavier elements in the core.

The brighter stars would use hydrogen more quickly and hence leave the Main Sequence before fainter ones, so that stars would gradually 'peel off' the Main Sequence, starting at the top end. This agrees with observation: the lower part of a main sequence quite similar to the Population I Main Sequence is seen in globular clusters, but the top part has gone completely. The red giants which are the brightest of the Population II stars cannot long have been shining with their present luminosity; they have probably spent most of their existence on the Main Sequence just above the present upper end of that sequence, and are now undergoing rapid evolution which will soon reduce them to blue dwarfs.

The subject is being actively pursued at the present time and it is hoped that soon we shall have achieved a clearer insight into the mechanisms of stellar evolution. (R.G.)

HIDALGO. An **asteroid** discovered in 1920. It has the largest known asteroid orbit, with aphelion as far from the Sun as Saturn. The orbit has exceptionally great inclination (42.6°) and eccentricity (0.66), and resembles that of a comet – it is quite closely similar to that of Tuttle's Comet. Long exposures with the 100-inch telescope on Mount Wilson have, however, failed to reveal any trace of coma.

HIGH-TEMPERATURE BELT. A region of the Earth's atmosphere at an altitude of about 35 miles. The temperature of the belt is about 80° C. compared with $-60°$ C. at 15 miles and $-30°$ C. at 55 miles. The high temperature of the layer is probably associated with the presence of ozone, a form of oxygen having three, instead of two, atoms in its molecule.

HOUR ANGLE. The hour angle of a celestial object is the time which has elapsed since its **meridian passage**. If the object has not yet crossed the meridian, i.e. is still in the eastern part of the sky, its hour angle is negative.

HYDRAZINE. A powerful reducing agent ($H_2N{-}NH_2$) sometimes used as a propellent in rocket motors, as are some of its derivatives such as *hydrazone*.

HYDROGEN. The chemical element with the simplest possible **atom** in which one electron moves around one proton. Hydrogen is a gas at ordinary temperatures and is only one-fifteenth as dense as air.

The Universe consists mainly of hydrogen, which provides the vast majority of the atoms both in stars and interstellar matter.

HYDROGEN PEROXIDE. A chemical sometimes used as an oxidant in rocket propulsion. Its molecule contains two atoms of hydrogen and two of oxygen. One oxygen atom can be split off and used to oxidize the fuel, leaving a water molecule behind. This reaction liberates a good deal of energy apart from the combustion of the fuel, and hydrogen peroxide has been used alone as a mono-propellent, but it has gone out of favour because of its tendency to explode spontaneously.

HYDROPONICS. The science of growing plants (including algae) without soil in a nutrient solution under natural or artificial light. It is a possible source of fresh food supply for long passages in space vehicles; as the plants absorb carbon dioxide and release oxygen, they also help to regenerate the air, but the system is handicapped by the large weight of water required for an installation capable of supplying even in part the needs of a space vehicle's occupants.

HYPERBOLA. See **Conic Sections.**

HYPERION. The seventh satellite of **Saturn.** It is one of the smaller satellites, having a diameter of perhaps 200 miles, It takes three weeks to complete one revolution in its orbit.

I

IAPETUS. The eighth satellite of **Saturn.** Its diameter is uncertain; some recent estimates put it at almost 2,000 miles, rather greater than was previously thought. Iapetus is interesting because it is much brighter near western elongation than near eastern, which indicates that all parts of its surface are not equally reflective.

ICARUS is perhaps the most interesting of the minor planets. At perihelion it can approach the Sun to 19 million miles, closer than the perihelion distance of Mercury; at aphelion it recedes well beyond the orbit of Mars. Although only a mile or two across, Icarus has been so thoroughly observed since its discovery in 1949 that there is no danger of its being lost, as some of the small 'Earth-grazers' have been. It has the smallest known **asteroid** orbit. It is named after the Icarus of Greek mythology who is said to have flown with artificial wings made of feathers and wax; when Icarus came too close to the Sun the wax melted and he fell to his death.

At perihelion the sunlit side of Icarus is red-hot; at aphelion its temperature is very low. If, as is likely, it spins with a period of rotation less than about two hours, then centrifugal force at the surface near the equator is greater than the almost negligible gravitational pull; any loose object placed on that part of the surface would therefore immediately drift off into space.

I.G.Y. See **International Geophysical Year.**

INERTIAL GUIDANCE. An inertial guidance system as used in a missile is able to measure the accelerations of the vehicle in all directions by means of accelerometers and hence, by means of *integrators*, to determine the vehicle's velocity and direction, the distance travelled and its altitude. The target co-ordinates are fed into the system before firing and it is able to deduce the geographic position of the vehicle and the distance and direction to the target throughout its flight. A correction can then be automatically made to put the missile on to its correct course. Such a system is completely self-contained and is invulnerable to enemy jamming; no ground facilities are required and no radiation is emitted, thus hindering enemy detection.

A typical system comprises three accelerometers mounted to measure North-South, East-West and vertical accelerations with their associated integrators. These are all mounted on a gyro-stabilized platform to maintain them in a fixed position despite changes in vehicle attitude and position. The servo-systems required to maintain the platform in its position must be exceptionally accurate and sensitive as all errors are cumulative and quite a small error in acceleration measurement can produce a large error in distance covered. The data are fed into a computer which works out the necessary correction and passes a signal to the main propulsion motor, the subsidiary rocket motors for pitch, roll or yaw control, or the aerodynamic controls if the vehicle is still within the atmosphere.

For very long range missiles (inter-continental) various special corrections must be introduced. For example, the Earth is not a perfect sphere but is slightly flattened at the poles to the extent of 13 miles in the radius of 4,000 miles. A further correction must be made for the fact that the Earth is revolving.

This system of guidance is best suited to static targets whose position is well known.

INFRA-RED RADIATION. Electromagnetic radiation of wavelength between 8,0C0 Angstrom units and 1/10 mm., including the entire wavelength range of radiant heat. See **Electromagnetic Spectrum.**

INTERCONTINENTAL BALLISTIC MISSILE. A long-range rocket weapon that is unguided over the main part of its trajectory. See **Missile.**

INTERFEROMETER, STELLAR. An instrument used by the physicist Michelson in 1920 to measure the apparent diameters of stars as seen from the Earth. It relies upon the fact that light waves travelling along very nearly parallel paths can cancel each other. The diameters of seven stars were obtained, all smaller than 0.06 seconds of arc.

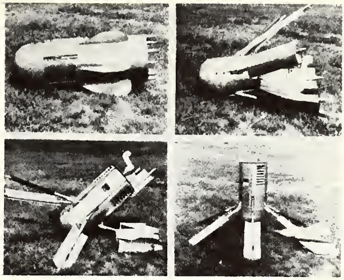
Although the design was very ingenious, the measurements were extremely tedious and difficult to carry out, and the instrument has not been used since 1920. Its importance lies in its direct check on the validity of other methods of finding stellar diameters.

INTERNATIONAL GEOPHYSICAL YEAR. The last I.G.Y. lasted for over 18 months from July 1956. During that time, scientists from over 60 countries co-operated in setting up new observatories and gathering a great volume of new data in many branches of science. Some of their achievements may not be known for years, but certain important results have already emerged.

Information gained from **artificial satellites** is discussed in the article relating to them. Views on the **atmosphere** have been profoundly modified, and the temperature of the ionosphere has been shown to be much higher than previously suggested. It has therefore been mooted that the Earth is a cool spot lying in the outer solar atmosphere.

The Antarctic has been studied by many expeditions, and over forty stations are still in use. The view is hardening that Antarctica consists of two separate land masses under one ice cap.

Many observations of the Sun were made, particularly during the eclipse of October 1958. (See **Sun.**) Exact determinations of the Earth's gravitational field have been made. From these, and from observations of satellite orbits, the precise shape of the Earth will be computed, although early results seem to be conflicting.



A ROBOT WEATHER STATION. The U.S. Navy's 'Grasshopper' is dropped by a self-detaching parachute and automatically opens and rights itself. It then records details of wind speed and direction, temperature, air pressure and humidity and transmits them in Morse code at intervals during 60 days. It was used in the Antarctic for I.G.Y. (*U.S. Navy*)

According to one unconfirmed interpretation, the Earth and some other planets show a flattening of their northern hemisphere in excess of that of the southern, and this is attributed to the action of unknown forces along their axes of rotation.

For other results, please refer to **Moon**, and **Van Allen Radiation.**

INTERSTELLAR MATTER. Material which exists between the stars in a galaxy, either in gaseous form or as minute solid particles. The total mass of interstellar matter in a spiral galaxy is comparable with the total mass of the stars.

The article on **galactic nebulae** describes the appearance of interstellar clouds, both dark and bright. Interstellar matter exists everywhere in the spiral arms, not only in these denser clouds. Certain lines in the spectra of binary and other stars do not move with the rest of the spectrum as the stars revolve; these lines do not originate in the stars themselves but in the interstellar matter between us and the stars. Close examination often shows the lines to be multiple. The multiplicity is caused by **Doppler shifts** that arise from the streams of interstellar matter moving at speeds of a few astronomical units per day relative to each other. Most of the interstellar

matter is hydrogen, at an average density of the order of one atom per cubic centimetre.

The number of **extragalactic nebulae** visible per square degree of sky falls off towards the galactic plane, and practically none can be seen within 5° of it because the light from them is obscured by interstellar matter in the galactic plane.

Besides the single atoms and molecules in interstellar space there are also 'grains', apparently made of ice. The size of these grains is about one ten-thousandth of a millimetre; this is deduced from the fact that they scatter blue light more than red, causing an overall reddening of the transmitted light. The light from distant stars is polarized: it is difficult to account for this without assuming the existence of metallic particles which are aligned by the weak interstellar magnetic fields.

Stefan's Law enables us to calculate the temperature of interstellar matter assuming it to behave as a **black body**: the result is about three degrees absolute, or —270° C. The assumption is, however, invalid, and a temperature many degrees higher is probable.

Intergalactic matter has been detected between galaxies that are closely associated. Very slight amounts of dark obscuring matter may exist between unrelated galaxies.

INTRA-MERCURIAN PLANET. Though it is now known that Mercury is the closest to the Sun of the major planets, it was formerly believed that a still closer planet existed; it was even given a name (Vulcan), and was thought to have a diameter of 1,000 miles, with a mean distance of 13,000,000 miles and a sidereal period of 19¾ days.

Le Verrier, whose calculations led to the discovery of Neptune, computed an orbit for Vulcan on the basis of some irregularities in the motion of Mercury. Various observations of the elusive body were reported; a French amateur, Lescarbault, stated that he had seen Vulcan in transit, and in 1878 two Americans, Watson and Swift, believed that they had recorded several previously unknown bodies by observing the neighbourhood of the Sun during the total solar eclipse of that year. However, the theory of relativity has cleared up the irregularities in the movements of Mercury, and it is now certain that Vulcan does not exist. It is not impossible that some minute asteroids may revolve at a mean distance from the Sun which is less than that of Mercury, but such bodies would be very difficult to detect. (P.M.)

IO. The innermost of the four large satellites of **Jupiter**. It is slightly larger than the Moon, having a diameter of 2,310 miles, and revolves once in its orbit in 42½ hours.

ION. An **atom** which has lost or gained electrons. Positive ions are atoms which have lost one or more electrons and have a resultant positive electrical charge. Negative ions are atoms which have gained electrons and are therefore negatively charged. For example, a proton is a positive hydrogen ion (a hydrogen atom which has lost its one electron).

Many singly or multiply-ionized atoms are present in stars as well as free electrons. The capture of a free electron by a positive ion is called *recombination* and is accompanied by an emission of radiation.

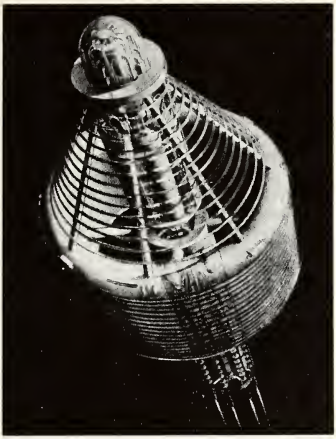
Ions differ from the corresponding normal atoms in their general properties. They are very reactive chemically, and move in an electric field towards an electric charge of sign opposite to their own. A stream of ions whose charges are of the same sign is equivalent to the flow of an electric current.

The symbols He^{+}, He^{++}, and Fe^{---} represent singly and doubly ionized helium and trebly ionized iron respectively.

ION ROCKET. A rocket propelled by the recoil from the ejection at high speed of electrically charged particles. It derives its energy from solar radiation, or from a nuclear power plant.

The maximum velocity which a rocket with conventional propellents can reach is limited by its **mass ratio** and **exhaust velocity.** The ion rocket design could provide exhaust velocities bordering on the speed of light, but such a rocket would accelerate very slowly and would spend weeks or months working up to high speeds. It must therefore be placed into an orbit about the Earth by ordinary step-rockets before its electrical propulsion can become effective.

The principle is very simple: either solar energy from large mirrors or solar batteries or a nuclear reactor is employed to drive a generator, whose output creates a strong



AN ION ROCKET DESIGN

electrical field. An easily ionizable substance (e.g. the metal caesium) supplies the **ions** which the electrical field repels so strongly that they are ejected with very great velocities.

In pushing the ions backwards, the rocket drives itself forwards. In one design which has been thoroughly worked out for a rather large payload, the rocket would accelerate in its orbit at 1 millimetre per second per second, so that after 1 hour its speed would have increased by 13 km per hour; each day it would add 311 km per hour, and would spiral away from the Earth; after 5,000 years it could theoretically reach half the speed of light. Needless to say, such a speed would inevitably carry it far beyond the solar system, and the Sun's radiation could not remain effective. On the other hand, a journey to Mars would take 260 days and could be made on solar energy alone.

The theoretical basis of the ion rocket is quite sound, but its weak thrust renders it impracticable.

IONIZATION. The formation of **ions**, or the degree to which an **atom** is ionized. Ionization of gases can be promoted by high-energy radiation such as light or ultraviolet rays, or by collisions of particles in thermal agitation. See **Spectroscopy**.

IONIZATION GAUGE. An instrument for measuring low pressures in gases. The strength of the electric current that flows between two terminals in a gas-filled tube depends upon the number of **ions** which are formed, and this in turn depends upon the pressure. The gauge is calibrated so that readings of the current also indicate the corresponding pressures of the gas.

IONOSPHERE. A region of the Earth's atmosphere extending roughly from 40 to 500 miles above the ground, merging into the *exosphere* above it.

Radio waves are expected to travel in nearly straight lines, and early experimenters were surprised that they could be received not only beyond the horizon of their transmitters but across thousands of miles round the Earth. An ionized layer in the atmosphere was postulated to account for this: such a layer would have the power of reflecting radio waves.

The ionosphere is now known to consist of *several* layers of ionized gases, whose altitudes are shown on the comprehensive diagram under **Atmosphere of the Earth**. The D region is only weakly ionized, and the chief reflectors are the E and F layers above it. During the night the F layer is single, but at sunrise it splits into two layers which drift apart and reunite at dusk. The E and F layers are sometimes named the Heaviside-Kennelly and Appleton layers respectively, after early investigators. Between them they reflect all radio waves which have wavelengths greater than five to thirty metres, the exact minimum value being variable. The E layer probably contains ionized oxygen, and the F layer ionized nitrogen as well.

The Sun exerts a controlling influence on the ionosphere. Its ultraviolet radiation ionizes the rarefied gases of the upper atmosphere, and the electron density there varies in step with the 11-year sunspot cycle and the 27-day period of the Sun's rotation (see **Sun**). Solar flares have profound effects, and cause short-wave radio fade-outs over the sunlit side of the Earth: the intense emission of X-radiation from a flare penetrates the E

layer and ionizes the lower strata where the air is denser. Radio waves are then absorbed instead of being reflected.

Flares are also responsible for magnetic disturbances. When a flare occurs there is a sudden magnetic disturbance called a *crochet*, followed about a day later by a magnetic storm as the charged particles emitted by the flare arrive. The time delay enables us to calculate the speed of these particles as about 1,000 miles per second. They also cause **aurorae**.

When meteors become incandescent in the F layer they produce large numbers of ions; this causes noticeable momentary increases in the intensity of radio reflections.

ISOTOPE. One of two or more forms of an element which differ in the number of neutrons contained in the nuclei of their **atoms**, but not in their chemical characteristics. For instance, **hydrogen** has three isotopic forms with 0, 1 and 2 neutrons respectively in their atomic nuclei. Some elements have as many as twelve isotopes, several of which may be radioactive.

J

JODRELL BANK. Experimental station of the Dept. of Radio Astronomy in the University of Manchester, with the world's largest radio telescope. The latter has an aperture of 250 ft., and can operate night and day irrespective of weather conditions. See **Radio Astronomy**.

JULIAN CALENDAR. The calendar instituted by Julius Caesar in 45 B.C. It was similar to the present system except that *every* fourth year was a leap year. This gave an average length of 365¼ days to the civil **year**, about 11 minutes longer than the tropical year. If this discrepancy had been allowed to build up indefinitely the civil year would have fallen progressively further behind the seasons, the spring in the Northern Hemisphere beginning in February, January, December ... When Pope Gregory XIII rectified the situation in 1582, ten days of accumulated error were dropped from that year; in the *Gregorian calendar* only such hundredth years as are divisible by 400 are leap years. 1900 was, therefore, not a leap year, but 2000 will be. The Gregorian calendar was not adopted in England until 1752, when the error was eleven days: the day after September 2 was called September 14. This occasioned some riots; people believed that their lives had been shortened by this Popish scheme of omitting certain dates, and crowds in Westminster chanted: 'Give us back our eleven days!'

The error in the Gregorian calendar is less than 1 day in 3,000 years.

JULIAN DATE. The system of time reckoning used in most astronomical calculations. Its only unit is the day: shorter intervals are expressed in decimals of a day. The starting point or **Epoch** of the Julian Period was January 1, 4713 B.C., and the date is measured in days from then. The Julian date corresponding to January 1, 1960, is 2,436,935. The Julian day starts at noon, twelve hours later than the civil day. To avoid confusion the civil date is often altered by half a day. Thus A.D. 2,436,934 commenced on 1960, January 0.5.

JUNE DRACONIDS. A **meteor** shower with maximum activity near June 28.

JUNO. One of the largest and brightest of the **asteroids**, having a diameter of 120 miles; it was the third minor planet to be discovered.

JUNO II. The four-stage launching vehicle of the *Pioneer IV* space probe. It was 76 ft. long and weighed 60 tons. Its 38 lb. payload was given a velocity of about 24,000 m.p.h.

JUPITER. An intermediate-range ballistic **missile** of the U.S. Army.

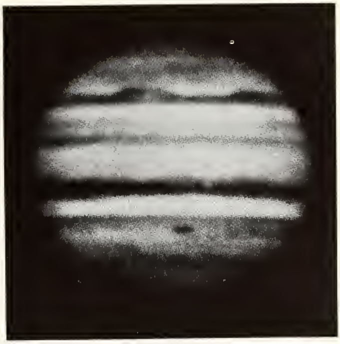
JUPITER is by far the largest and most massive of the planets and may be considered the most important member of the Sun's system. Despite its great distance from the Earth, it appears as a brilliant object in our skies, outshining all other planets apart from Venus and – on rare occasions – Mars. Unlike Mars, it comes to opposition almost every year, having a mean synodic period of 399 days.

ORBIT. Jupiter's mean distance from the Sun is 483 million miles, the perihelion and aphelion distances being respectively 460 and 507 million miles. The orbit is inclined at 1°.3 to the ecliptic. The orbital velocity is about 8 miles per second. Owing to its great mass, Jupiter has a very marked effect upon the motions of other members of the solar system, including the asteroids and comets.

DIMENSIONS AND MASS. Jupiter is appreciably flattened at the poles, the equatorial and polar diameters being 88,700 and 82,800 miles respectively. This compression is obvious in any small telescope. Yet although Jupiter's vast globe could contain 1,312 Earths, its mass is only 317 times that of the Earth. The density is relatively low, only 1.34 times that of water, and at once indicates that Jupiter is a world totally unlike our own. The surface gravity is 2.64 times that of the Earth, and the escape velocity is 37 miles per second. This high value means that landing upon the surface would be impossibly dangerous, even in the absence of other hazards.

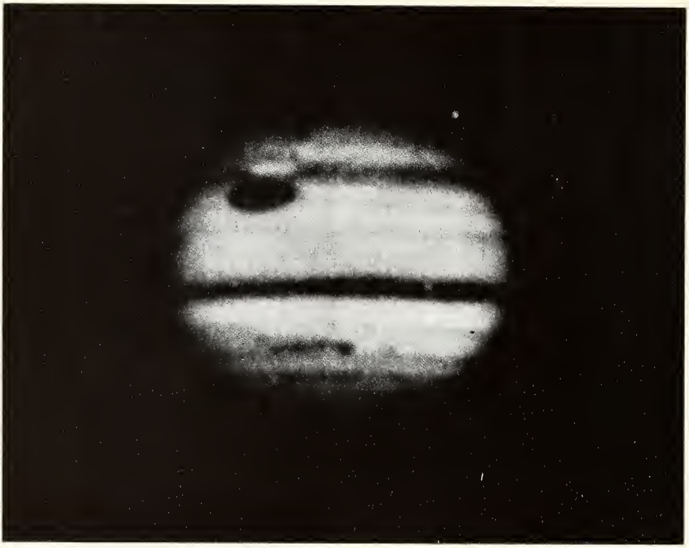
TELESCOPIC APPEARANCE. Jupiter is a fascinating object in even a small telescope. The general hue of the disc is yellow, and there is much detail to be seen. The straight belts parallel to the equator are most conspicuous, and there are also spots and other more complex features. Yet the surface details are not permanent. They alter constantly, and it is unusual for any particular feature to persist in recognizable form for more than a few days. Even the belts vary in prominence and structure. In 1951, for instance, the south equatorial belt was obscure, whereas by 1956 it had become almost as conspicuous as the north equatorial belt.

One or two features have longer lifetimes. Most famous of these is the Great Red Spot, which first became prominent in 1878, although indicated on drawings made much earlier. Though it is no longer conspicuous, it and its associated Hollow are still to be seen. Another long-lived feature was the South Tropical Disturbance, first seen in 1901 and last recorded with certainty in 1940. In late 1955 a fresh disturbance was reported in this zone.



Nomenclature of the zones and belts of Jupiter.
SEB = South Equatorial Belt.
STB = South Temperate Belt.
SSTB = South South Temperate Belt.
Similarly for the northern features.

ROTATION. The inclination of the equator to the orbit is only 3°.1. The rotation is extremely rapid; Jupiter has in fact a shorter 'day' than that of any other planet, 9 hours 50 minutes 30 seconds in the case of the equatorial zone. However, this period is not constant for all parts of the planet, which is proof – if proof were needed – that the surface



JUPITER. The shadow of its satellite Ganymede can be seen slightly above and to the right of the Great Red Spot, which is especially prominent as this photograph was taken in blue light.
(*Mount Wilson – Palomar*)

is not hard and rocky. The quick rotation means that the spots and other features can be seen to drift almost perceptibly across the disc.

It has been found convenient to adopt a system of nomenclature for Jupiter based upon the differing rotation periods. System I, bounded by the north border of the south equatorial belt and the south border of the north equatorial belt, has the period given above; System II, the rest of the planet, has an average period of 9 hours 55 minutes 41 seconds.

Even this is an over-simplification. Various features, such as the Red Spot, have their own rotation periods. The case of the old South Tropical Disturbance is of particular interest; its period was less than that of the Red Spot, so that at intervals it caught up and passed the Spot. Interactions were obvious. The Spot seemed to attract the Disturbance, the ends of the Disturbance being accelerated as they approached the Spot and retarded after they had passed it, while the Spot itself was accelerated.

There have also been 'circulating currents' as was the case in the south tropical zone during 1919–20 and 1931–34, and altogether the study of these peculiarities of Jupiter's rotation period is an important branch of planetary astronomy.

TEMPERATURE. Jupiter was formerly believed to be self-luminous, at least in part, and to be extremely hot. Modern research has proved otherwise. The temperature is in fact about −138° C., which is about what would be expected for a non-luminous body revolving round the Sun at such a distance. The satellites must of course be equally cold, since they can draw no appreciable heat from Jupiter itself.

CONSTITUTION OF THE GLOBE. According to R. Wildt, Jupiter is made up of a central metallic core 37,000 miles in diameter, surrounded by an ice layer 17,000 miles thick which is in turn overlaid by a dense atmosphere 8,000 miles in depth. The outer atmosphere can be analyzed, and has proved to be very rich in methane and ammonia. There is no mystery about the presence of hydrogen compounds of this sort, since Jupiter's great mass enabled it to retain all its original hydrogen.

Recently, Wildt's model has been questioned. W. R. Ramsey considers that Jupiter is composed mainly of hydrogen, the pressure at great depths being so tremendous that the hydrogen starts to behave in the manner of a metal. The core of hydrogen would have a diameter of 76,000 miles. At the moment it is impossible to decide between these two theories, and both may prove to be wrong; but we can be certain that any form of life on Jupiter is out of the question.

JUPITER AS A RADIO SOURCE. In 1955, it was discovered that Jupiter is a 'radio star'. As a source of radio waves it is indeed quite powerful, the traces being sometimes stronger than those from the **Crab Nebula**. The discovery was more or less accidental, and was certainly unexpected. So far the origin of these radio emissions is obscure. Nor has it been possible to trace the radio source to any particular region of Jupiter, though on several occasions it has been thought that increased radio noise has coincided with the passage across the central meridian of some definite spot or disturbance.

SATELLITES. Jupiter is attended by twelve satellites. Four of these (Io, Europa, Ganymede and Callisto) are visible in any small telescope, and have even been seen without optical aid by exceptionally keen-sighted observers. The remaining eight are very faint.

Callisto is the largest of the four, but it is also the least massive, and must be constituted very differently from a body such as the Moon. Ganymede, which has a fairly high escape velocity, might possibly be expected to retain some trace of an atmosphere; but none has been detected, and it now seems probable that it, like the other satellites, is devoid of any atmospheric mantle.

Physical data of the major satellites are of interest:

Satellite	Io	Europa	Ganymede	Callisto
Diameter (*miles*)	2,310	1,950	3,200	3,220
Mass (*Moon*=1)	1.09	0.65	2.10	0.58
Density (*Water*=1)	2.7	2.9	2.2	1.3
Escape Vel. (*Miles/sec.*)	1.5	1.3	1.8	0.9

The fifth satellite, known semi-officially as Amalthea, revolves round Jupiter at a mean distance of only 113,000 miles. It is a small world, only 150 miles in diameter. The distances of the four major satellites range from 262,000 miles (Io) to 1,170,000 miles (Callisto); their eclipses, occulations, transits and shadow transits may be followed with a small telescope, thus providing the observer with a never-ending source of interest. The remaining satellites are unnamed and lie at distances of between 7 million and 14 million miles from Jupiter; owing to perturbations by the Sun their orbits are not even approximately circular. All are minute (XII, discovered in 1951, has an estimated diameter of only 14 miles); VIII, IX, XI and XII have retrograde motion. It is possible that they are captured asteroids.

EXPEDITIONS TO JUPITER. From what has been said, it is clear that there can be no question of landing on Jupiter either now or in the future. The Giant Planet is an alien body; the nature of the surface, the intense cold, and the high gravity and escape velocity rule it out. It is not impossible that landings will eventually be made upon some of the satellites, but even these bodies are most inhospitable. At speeds at present achieved, a round trip to Jupiter would take many years. (P.M.)

K

K CORONA. The inner region of the solar corona. See **Sun**.

KEPLER'S LAWS. The three laws of planetary motion formulated by Johann Kepler early in the 17th century on the basis of his analysis of Tycho Brahe's observations. They are:

1. *The planets move in ellipses, with the Sun at one focus.* (See **Conic Sections.**)

2. THE LAW OF AREAS: *the line joining the Sun and a planet sweeps out equal areas in equal times.*

3. THE HARMONIC LAW: *the square of the time of revolution (in years) of any planet is equal to the cube of its mean distance from the Sun (in astronomical units).*

The Law of Areas enables changes in a planet's orbital speed to be calculated. From the Harmonic Law we can obtain either the distance or period of revolution, provided the other is known from observation.

The laws also apply to satellites, as the latter may be regarded as planets of their primary. It follows from the Harmonic Law that artificial Earth satellites whose mean distances are very small must have very short periods of revolution.

KINETIC ENERGY. The energy possessed by a moving body by virtue of its motion. See **Energy**.

KIRKWOOD GAPS. Owing to its great mass, Jupiter exerts strong perturbing forces on the **asteroid** orbits. A minor planet whose period is a simple fraction of that of Jupiter repeatedly suffers the same perturbations; the cumulative effect is that its orbit is changed so that its revolution period is no longer a simple fraction of Jupiter's. A graph showing the number of asteroid orbits for any given length of period displays marked minima called the Kirkwood Gaps for those simple-fraction periods.

L

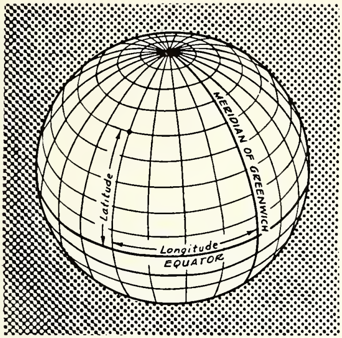
LANDING TECHNIQUES. When a spaceship reaches its destination it must, in order to land intact, destroy its velocity relative to the world on which it is to land. To do this in the absence of an atmosphere, the rocket motors must be used; but if there is a gaseous envelope it may be used to provide a frictional braking force. (See **Braking Ellipses.**)

A powered landing requires almost exactly as much propellent as is needed to take off into space from the same place. The rocket has first to be orientated so that the thrust from its motors, when fired, is *away* from the landing point. A radar altimeter indicates height above ground and is coupled to a computer which controls the motors throughout the manoeuvre. Even in a manned rocket, the strain on the crew of the deceleration and the almost inevitably fatal consequences of a small error of judgment render manual control of the operation completely impracticable.

On the other hand, turning the rocket around or otherwise reorientating it is an extremely simple matter. All that is necessary is that there should be a small, heavy wheel mounted somewhere in the cabin with its axis at right angles to the axis of the rocket. If this wheel is made to spin by a handle or treadle, rather like a potter's turntable, the whole rocket will slowly revolve in the opposite direction to that in which the wheel is spinning, and will continue to do so until the wheel is stopped. Even for the largest rocket this will require very little work. The explanation of this fact lies in the principle of the conservation of **angular momentum**; no part of an originally steady rocket can be made to rotate without producing an equivalent rotation of other parts in the opposite direction.

LATITUDE. The latitude of a point on the surface of a rotating sphere or ellipsoid is the angle at the centre of the body between the point and the equator.

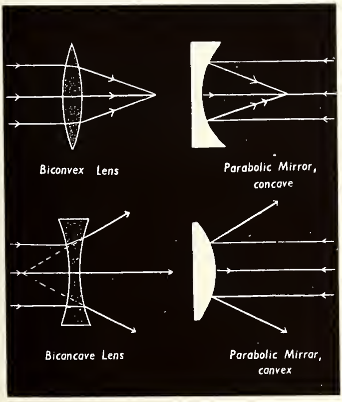
LATITUDE, CELESTIAL. The angle in degrees between a point on the **celestial sphere** and the nearest point on the **ecliptic**. It is



reckoned positive northwards from the ecliptic and negative southwards.

LENS. A disc of glass, or other transparent substance, with curved surfaces. The surfaces are convex or concave, or in some cases one of them may be flat.

A *positive* lens causes light which enters it in a parallel beam, as from a distant star or planet, to converge upon a *focus*, where an image of the distant object is formed. The distance between the lens and the image is the *focal length.*



A *negative* lens does not bring parallel rays to a focus but causes them to diverge. Such lenses have been used in lieu of eyepieces in very crude telescopes, such as the early instruments and those sold as toys.

A single lens has various defects, including **chromatic aberration** and *spherical aberration.* By a tactful combination of lenses made of different types of glass it is possible to get rid of the most troublesome features of the simple lens, at least so far as the central part of the image is concerned.

LEONIDS. A **meteor** shower occurring annually about November 16; very intense returns were seen in 1799, 1833 and 1866, when in certain regions the estimated number of meteors reached 200,000 per hour.

LIBRA, FIRST POINT OF. See **Celestial Sphere.**

LIBRATIONS OF MOON. Tidal friction has made the period of axial rotation of the Moon equal to its period of revolution round the Earth. This means that the same hemisphere of the Moon is always turned towards us.

However, we can at various times examine more than half the lunar surface; only 3/7 are permanently concealed. Though the rate of axial spin is constant, the Moon has an orbit of appreciable eccentricity, and this results in a variable orbital speed. Consequently, the axial spin and position in orbit become periodically out of step, and the Moon appears to tilt very slightly to the East or West, exposing first one limb and then the other. This is called libration in longitude. There is also a libration in latitude, due to the fact that the Moon's orbit is slightly inclined to that of the Earth. (See **Moon.**)

LIFE. A substance may be said to be living if it can add to itself by chemical exchanges with its environment (growth and metabolism), can detach part of itself to exist separately (reproduction), and can react to stimuli (irritability). We cannot add to this definition of what constitutes living matter if we want it to embrace the simplest protozoa, algae, bacteria and such things as a fertilized hen's egg. On the other hand, if we accept the definition as it stands, life could exist in forms that bear no resemblance to terrestrial organisms. Neither oxygen nor water is

theoretically essential, and life is conceivable in conditions which no known form could survive.

The only absolute prerequisites are the presence of carbon or silicon and a fair variety of other elements, and a temperature neither very cold nor very hot. A living substance must consist of extremely elaborate molecules, and only carbon and – to a much lesser extent – silicon atoms are capable of linking themselves in the long and branching chains and rings which provide the framework for such molecules. Extreme cold inhibits chemical activity, and heat much above the boiling point of water breaks up most complicated molecules; but a moderate temperature can support just that level of chemical interchanges which is most likely to result in the synthesis of living matter. Chance would play a part in this, but chance in the long run obeys inexorable laws; the evolution of higher organisms from simpler ones depends very largely on the systematic effect of great numbers of accidental events, and precisely similar principles can lead to the evolution of complex molecules from simpler matter.

Life on stars is impossible, because they are too hot. But life on bodies like the planets cannot be ruled out on the grounds that their atmospheres are 'unsuitable', that pressures are too great or too low, that there is no water or that 'poisonous' substances abound. So far as the planets are concerned, temperature alone is the factor that makes life in certain localities virtually impossible. Where life does perhaps exist, it is most unlikely to resemble earthly forms even to an extent that would enable us to fit it into our plant or animal kingdoms. We already know viruses in the shape of crystals, spores like microscopic golf balls that can survive temperatures of —220°C., fungi that do not breathe oxygen, plants without green chlorophyll, fish and plankton that can withstand pressures of thousands of pounds per square inch, highly-developed non-cellular animals that thrive in dark, boiling springs, bacteria that need no water; we know that living matter can look like jelly, like yeast, or like a sponge. It would be very rash to say where life is possible and where it is not. (M.T.B.)

LIGHT. See **Electromagnetic Radiation, Electromagnetic Spectrum,** and **Spectroscopy** (section on Colour and Wavelength).

LIGHT YEAR. The distance travelled in one year by light, which covers 186,000 miles in one second. It is equal to 5,880,000,000,000 miles. See table under **Distances.**

LIMB. The edge of the visible disc of the Sun, the Moon or the planets.

LINE OF FORCE. See **Magnetism.**

LOGARITHMIC SCALE. A scale that is often used in graphs when quantities have to be represented that range from very small to very large values. The height scale in the diagram of the **Atmosphere of the Earth** is an example of its use in this book.

LONGITUDE. The longitude of a point on the surface of a rotating sphere is the angle at the pole between the **meridian** through the point and another meridian which marks the arbitrary zero of longitude (in the case of the Earth, the **Greenwich Meridian).**

LUNAR PROBE. A device designed to make observations of the Moon and its environment either by orbiting it or by landing instruments upon it. See **artificial satellite.**

LUNIK. The name given to Russian **lunar probes.** The first entered an orbit round the Sun.

LYMAN SERIES. A series of lines in the ultra-violet region of the spectrum of the hydrogen atom. See **Spectroscopy.**

β-LYRAE. An eclipsing **binary star** whose light variations, which have a period of nearly 13 days, can be followed by the naked eye. See **Variable Star.**

LYRIDS. A **meteor** shower occurring annually about April 21. It is now quite weak, but has been traced back to 15 B.C.

M

MACH NUMBER. The velocity of an aircraft or other vehicle moving in an atmosphere divided by the velocity of sound near the craft. For instance, at the surface of the Earth sound travels at about 750 m.p.h.; Mach 3 would therefore be $3 \times 750 = 2{,}250$ m.p.h. The speed of sound varies with temperature and therefore with altitude. The diagram illustrating **Atmosphere of the Earth** shows the exact form of the variation.

MAGELLANIC CLOUDS. Two irregular galaxies, the nearest neighbours to our own stellar system. The naked eye sees them as faintly luminous patches. The *Large Magellanic Cloud* has a well-marked axis and is less irregular than the *Small Magellanic Cloud*, whose photograph appears under **Extragalactic Nebulae.**

Both clouds contain a remarkably high proportion of Cepheid **variable stars**, as well as O and B stars and some K type **supergiants.** The star of greatest intrinsic brightness known to us lies in the larger cloud; it is a very peculiar variable, *S Doradûs*, whose maximum absolute magnitude is -9.

The clouds are in motion around our own Galaxy. They both contain interstellar dust which affects the light of more distant galaxies seen through the clouds. **Globular clusters** and **novae** have been observed in them, together with the recently discovered **RR Lyrae** stars which furnish us with the most accurate distance estimates we have: both galaxies lie at about 50,000 parsecs from us.

MAGNETIC STORM. A period of violent fluctuations in the Earth's magnetic field caused by **solar flares.** The fluctuations induce electric currents in the **ionosphere** and in long distance cables and severely interrupt radio and telephone communications.

MAGNETISM. The attribute of magnets. A magnet is a piece of metal (usually iron) which attracts other pieces of similar metal to itself.

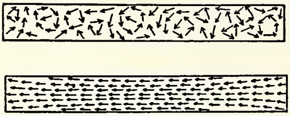
The atoms of such metals are tiny natural magnets, but normally point in haphazard directions, so that they annul each other's effect. If some or all of these tiny magnets are aligned they reinforce each other's effect and the piece of metal containing them is magnetized. Such an alignment can be brought about by an already existing magnet, or by electric current passing through loops of wire around the metal.

Every magnet has two *poles.* The Earth itself acts as a magnet whose poles are near its geographic poles. A magnet which is suspended so that it is free to swing will set itself with its *north pole* pointing roughly north, and its *south pole* pointing south. Similar poles of two magnets repel each other, poles of opposite kind attract each other.

It is impossible to have a north pole without a south pole. Cutting a magnet simply results in two smaller magnets, each with two poles. The region round a magnet where its influence is appreciable is termed a *magnetic field.*

The pattern of a magnetic field is often represented by means of *lines of force.* A line of force is the path along which a free north pole would travel if such a thing could exist. At any point within a field, a compass needle will tend to lie along the line of force which passes through its centre, and the line can be traced by moving the compass needle further and further along it.

All lines of force run from one pole to the other, but they are not straight as a rule. The lines of force of the Earth's magnetic field all converge on a point which appears to lie within it below north-eastern Canada, and this point is one of the Earth's two magnetic poles, the other one being in the Antarctic. A compass needle suspended above the ground immediately over the poles assumes a vertical position. The magnetic poles are not stationary but move in small circles with a period of about 500 years. There has also been a less regular long-term movement; the direction of the Earth's field may once have been the reverse of what it is now, and during the last 1,000 million years the magnetic poles have wandered considerably both in relation to the land masses and to the Earth's axis of rotation. Some rocks which were deposited



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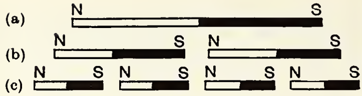

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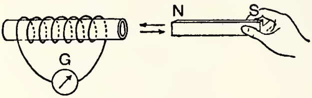

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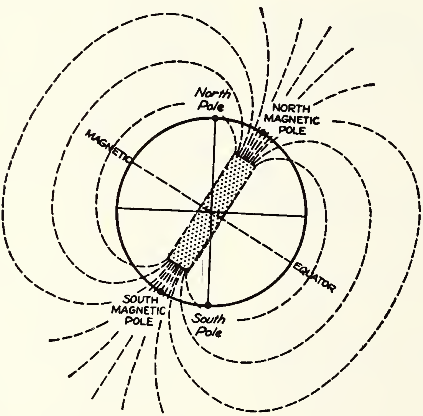


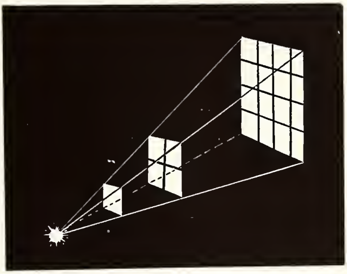
4

SOME BASIC FACTS OF MAGNETISM. (1) Each molecule in a piece of iron is a small magnet. When the molecules are aligned they act together, and the piece of iron becomes a magnet. (2) If a magnet is split in two, it yields two smaller, complete magnets. (3) If a conductor like a wire moves in a magnetic field (or if the field moves relative to the conductor) a current is made to flow through the conductor. (4) The Earth's magnetic field is shaped *as if* a gigantic bar magnet were buried within the Earth.

during this period still retain magnetism from which past patterns of the Earth's field can be deduced. Nothing definite is known about the reasons for these changes in the field.

The Sun and many other stars have magnetic fields whose detection is based on the **Zeeman effect.**

MAGNETOGRAPH. An ingenious instrument for mapping the magnetic field of the Sun. Its action depends on the **Zeeman effect.** It scans the Sun in narrowly spaced lines and measures the Zeeman splitting of the spectral lines continuously. The measurements are recorded in a trace which wanders above or below the scanning line according to the sign and strength of the magnetic field at each point along the line.



A certain area is illuminated by a source of light. At double the distance the same amount of light would be spread over an area four times as large, i.e. the intensity of illumination is reduced to a quarter. We say that the intensity of the light received from a source is *inversely proportional to its distance.*

MAGNITUDE. The brightness of a star. *Apparent* magnitude indicates the brightness of a star as we see it; *absolute* magnitude is a measure of its intrinsic luminosity, independent of the star's distance.

APPARENT MAGNITUDE. Some of the brightest stars in the sky have brightnesses of the *first* magnitude. This is defined rather arbitrarily as the brightness of a candle flame at a distance of 1,300 feet. Stars of the *second* magnitude are fainter than the first by a factor of two and a half; those of the *third* magnitude are that much fainter again, and so on. A difference of five magnitudes means that one star is precisely a hundred times as brilliant as another. The faintest star visible to the naked eye on a dark and clear night is of the sixth magnitude. The largest telescope in the world can photograph stars of the twenty-third magnitude.

It should be noticed that the *fainter* an object is, the *larger* its numerical magnitude.

A few stars are brighter than the first magnitude, and the scale is extended to zero and beyond into negative magnitudes. The Sun's magnitude is —27.

ABSOLUTE MAGNITUDE. The above takes no account of the distances of the objects concerned. The absolute magnitude of a star is the apparent magnitude it would have *if it were placed at a distance of 10 parsecs from us.* The Sun would there appear dimly visible to the naked eye as a star of magnitude 4.7; other stars, vastly more luminous, range up to —9.

PHOTOGRAPHIC AND VISUAL MAGNITUDES differ somewhat because the photographic plate is relatively more sensitive to blue light than the human eye, and so sees blue stars brighter and red stars fainter than the eye. Although this is in many ways a nuisance, it has been turned to good account and makes it possible to describe the colours of stars numerically. This point is dealt with under **Colour Index.**

BOLOMETRIC MAGNITUDE refers to the total brightness of a star, not only in the visible part of the spectrum, but at all wavelengths. It is discussed under its own heading.

DISTANCE MODULUS. This is defined as the apparent *minus* the absolute magnitude of a star. The apparent magnitude can always be measured by direct observation, and the

absolute magnitude is often deduced from other evidence. Both together give the distance of the star.

Dist. Modulus (*magnitudes*)	*Distance* (*parsecs*)
14	6,000
16	16,000
18	40,000
20	100,000
22	250,000
24	600,000

MAIN SEQUENCE. See **Hertzsprung-Russell Diagram.**

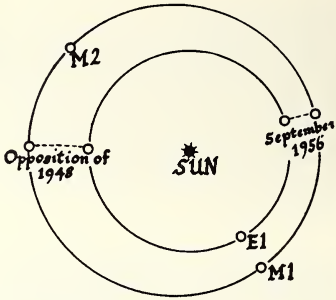
MARE CRISIUM. One of the smallest and most conspicuous of the lunar 'seas' (see **Moon**). Considerable interest was aroused in 1953 by a claim that a natural bridge had been discovered in the south-eastern wall of the Mare Crisium, but the existence of such a feature is definitely disproved.

MARS is generally regarded as the most interesting of the planets. There is an excellent reason for this; although smaller and colder than the Earth, and with a thinner atmosphere, it does not appear to be hopelessly unfriendly towards life. Fifty years ago, indeed, Mars was believed to be inhabited by advanced beings. Though this idea has now been discarded, there is at least strong evidence in favour of the existence of vegetation.

ORBIT. Mars is the first of the *superior* planets lying beyond the orbit of the Earth. The mean distance from the Sun is 141.5 million miles. The perihelion and aphelion distances are 129 and 154 million miles respectively, from which it can be seen that the orbit is of considerable eccentricity (0.093). The period of revolution is almost exactly 687 days, while the orbital inclination is 1°.9, and the mean orbital speed 15 miles per second, as compared with the 18.5 of the Earth.

Mars comes to opposition at intervals which average 780 days, and detailed study of its surface features is therefore possible only for a few months every alternate year. When at its closest, as in September 1956, Mars attains a magnitude of —2.8, greater than that of any other planet apart from Venus.

For obvious reasons, Mars can never appear dichotomized or crescent, but when some way from opposition it presents a distinctly gibbous phase. This effect was originally detected by Galileo.



OPPOSITIONS OF MARS are not all equally favourable for observations of the planet owing to the eccentricity of the orbits. E 1 represents the Earth; M 1 the nearest and M 2 the farthest possible positions of Mars. (*P. Moore*)

ROTATION. The rotation period of Mars, 24 hours 37 minutes 22.65 seconds, is known with great accuracy. The Martian 'day' is therefore only about half an hour longer than ours, and the axial inclination (25° 12′) is also very similar. As on Earth, the southern summer occurs near perihelion, so that the southern hemisphere experiences greater extremes of temperature than the northern.

DIMENSIONS AND MASS. Mars has a diameter of 4,200 miles, roughly half that of the Earth. The density is 4 times that of water, corresponding to a mass 0.11 and a surface gravity 0.38 of that of our world. The escape velocity is 3.1 miles per second.

Since there are no oceans on Mars, the land surface of the planet is roughly equal to that of the Earth.

SURFACE FEATURES. The markings on Mars are hard and generally permanent, so that – unlike those of Venus – they are true surface phenomena. The planet reveals broad reddish-ochre tracts known commonly as 'deserts', as well as darker areas and well-defined whitish polar caps. The most noticeable dark areas are the Syrtis Major in the southern hemisphere and the Mare Acidalium in the northern, both of which can be seen with a 3-inch telescope under favourable conditions.

THE POLAR CAPS. The whitish caps covering the poles are probably the most conspicuous of all Martian features. For many years there was some doubt as to whether they consisted of snowy material or of solid carbon dioxide, but the question was cleared up in 1948, when spectroscopic lines due to ice were detected. It would however be misleading to draw too close an analogy to the terrestrial polar caps. On Earth, the thickness of the icy deposit amounts to many feet; on Mars it cannot be more than a few inches at most.

The caps take part in a regular seasonal cycle. During spring and early summer, the appropriate cap shrinks rapidly; the southern mantle has in some years vanished entirely.

FOUR VIEWS OF MARS. The white area near the top is the South Polar Cap. The triangular dark area in the third and fourth photographs is the Syrtis Major.

During the period of decrease, the outline of a cap becomes irregular. Certain areas appear to retain the deposit for longer than others, and this is attributed to differences in level; there may be plateaux several thousands of feet in height. Another interesting phenomenon is the dark fringe which appears round the edge of a cap during the shrinkage. This has been shown to be a real band, not a mere contrast effect, and it may be due to the moistening of the ground by the melting of the polar frosts.

THE DARK AREAS. Until the last decade of the nineteenth century, the dark areas of Mars were thought to be seas. This theory has become quite untenable, and it now appears more probable that the areas are covered with lowly vegetation of some sort. This hypothesis is supported by the fact that as a polar cap shrinks, the dark areas seem to show signs of activity, as though the plants were being affected by the release of moisture into the thin, dry air. What has been described as 'a

wave of darkening' spreads from the polar zone towards the equator. Non-seasonal variations also occur in certain places, indicating perhaps a temporary spread of vegetation on to the surrounding desert; the small patch known as the Solis Lacus is particularly notorious in this respect.

It must however be added that other theories have been put forward to explain the dark areas. Arrhenius rejected vegetation in favour of hygroscopic salts, while in 1954 it was suggested that the areas may be made up of ash ejected from active volcanoes. There are obvious disadvantages to these theories, and it is fair to conclude that the existence of lowly vegetation on Mars is very probable, though at the moment direct proof is lacking.

can exceed 30° C., the dark areas being somewhat warmer than the deserts. On the other hand, the nights, even at the equator, must be bitterly cold, since the thin atmosphere is unable to blanket in much heat. The minimum temperature at the poles may be as low as —90° C.

ATMOSPHERE. Mars possesses an atmosphere of reasonable density. The ground pressure is in the order of 7 cm. of mercury, rather less than 1/10 of the pressure of our own air at sea-level. This means that the atmosphere is dense enough to allow future space-travellers to dispense with pressurized suits, and it also acts as an efficient meteor screen. Moreover, it protects the surface of the planet

MARS. Twin photographs taken with the 200-inch telescope in blue light (left) and in red. Only red light penetrates the thin Martian atmosphere sufficiently well to show surface details clearly.
(*Mount Wilson – Palomar*)

from short-wave solar radiation. The Martian air is indeed remarkably opaque to short-wave radiation, owing to the presence of the so-called *Violet Layer* at a height of from 7 to 10 miles above the surface. The composition of this layer is uncertain, but of its existence there is no doubt. At irregular intervals it clears away, to re-form some days later. When the violet layer is absent, the seasonal development of the dark areas is halted, indicating that the vegetation is being damaged by the solar bombardment. Major clearings of the layer took place in 1941 and in 1954.

Even if it were made of pure oxygen, the atmosphere of Mars would be too thin to be

THE BRIGHT AREAS. Five-eighths of the Martian surface are occupied by the reddish-ochre tracts known generally as the 'deserts'. Needless to say, there is no suggestion that Mars is a world of sandy wastes punctuated by oases. There is certainly no sand, and it is probable that the reddish colour is due to some mineral. However, there is no harm in describing the ochre areas as 'deserts' in the broader sense of the word.

TEMPERATURE. Since Mars lies beyond the orbit of the Earth, we must expect it to be comparatively cool, but it is certainly not a frozen world. The temperature at the equator

breathed by terrestrial creatures, but in fact the amount of free oxygen is too small to be detectable. Water vapour is also in short supply. In 1947 it was discovered that carbon dioxide is present in small quantity, but on the whole it seems that the bulk of the atmosphere must be made up of nitrogen.

CLOUDS. Clouds in the Martian atmosphere are not infrequent. Those of high altitude are due probably to ice crystals, while the more conspicuous yellow clouds, at altitudes of from 2 to 3 miles above the surface, seem to be dust-storms. Occasionally a yellow cloud may become very prominent; in 1911, for instance, there was a vast cloud that hung over much of the southern hemisphere, and persisted for months.

Such clouds are not easy to account for. Winds on Mars are very moderate, and appear incapable of raising giant dust-storms; nor is vulcanism likely. It is of course clear that rainfall upon Mars can never occur.

THE CANALS. In 1877 Schiaparelli drew attention to some curious straight lines crossing the ochre tracts, linking dark area with dark area and forming a planet-wide network. These 'canals' were studied in detail by Lowell, who believed them to be artificial waterways, built by intelligent Martians to irrigate the arid regions of their world. This theory has now been rejected, particularly as the canals are not so narrow or so regular as they appear in Lowell's drawings. They take part in the general seasonal cycle, from which it is inferred that they are composed of the same material as that which makes up the dark areas. It must however be admitted that they are very curious features, quite unlike anything else in the solar system.

SATELLITES. Mars has two satellites, Phobos and Deimos, both discovered during the favourable opposition of 1877.

These tiny worldlets are difficult telescopic objects, even when Mars is near opposition. Each revolves almost in the plane of the equator, so that to a Martian observer Phobos would be invisible from latitudes higher than 49° north or south, the limiting latitude for Deimos being 75°. Phobos has a revolution period shorter than the axial rotation period of its primary (a case unique in the solar system), and would appear to rise in the west and set in the east, crossing the sky in only 4½ hours and going through more than half its cycle of phases in the process. Deimos would remain above the horizon at any one place for 2½ days, but would hardly show a perceptible disc. From Mars, it would appear rather larger but considerably dimmer than Venus does to us.

	Phobos	*Deimos*
Mean distance from centre of Mars, in miles	5,800	14,600
Period	7d. 39m.	30h. 18m.
Orbital Eccentricity .	0.017	0.003
Diameter in miles . .	10 ±	5 ±

Despite their small size, Phobos and Deimos may well be of great importance to us in future centuries, since they form perfect natural 'space-stations' orbiting Mars.

LIFE ON MARS. Though there is strong evidence of vegetation on Mars, the thin atmosphere seems to preclude the existence of advanced forms of life. Even animals seem to be out of the question, and Lowell's idea of a planet-wide civilization must be rejected. (But see also **Life**.)

However, there is no reason to suppose that Mars will prove unduly hostile to future travellers. If men can learn how to journey through space, they should have no real difficulty in surviving upon arrival, despite the unbreathable atmosphere and the scarcity of water. Mars is at least far more inviting than Venus or the Moon, and the indications are that it is a living and not a dead world. (P.M.)

MASS is defined under **Gravitation**.

MASS RATIO.

$$\textit{Mass ratio} = \frac{\textit{take-off mass of rocket}}{\textit{all-burnt mass of rocket}}$$

The mass ratio determines the final velocity attainable by the rocket in terms of its **exhaust velocity**. If the mass ratio is 2.7 to 1, (i.e. if the propellent accounts for just under two-

An imaginary view of Mercury's half-molten surface. It *could* look like that, but it could also be entirely different. (*Hulton Press*)

thirds of the full weight of the rocket), the final velocity, ignoring **gravitational loss** and other minor factors, is equal to the exhaust velocity; if it is 7.4 to 1, the rocket can travel twice as fast as the exhaust velocity, while a ratio of 20 to 1 would give it three times the exhaust velocity. The first figure was already bettered in the V–2 rocket. The second might conceivably be achieved in the future. The third would require so light a structure – not to mention any **payload** – that it could not possibly support the strain of high accelerations.

MATADOR. A surface-to-surface winged tactical missile of the U.S. Air Force.

MEAN SUN. In its elliptical course round the Sun, the Earth accelerates as it moves towards the Sun and slows down as it recedes from it. This causes the Sun's apparent motion in the sky to vary throughout the year. The *Mean Sun* is an imaginary celestial body which moves through the sky with a constant speed equal to the average speed of the true Sun. The interval by which the true Sun is ahead of or behind the Mean Sun is called the *Equation of Time*. It never exceeds seventeen minutes, and four times a year it is zero. It is tabulated in almanacs.

MERCATOR'S PROJECTION is used to portray the curved surfaces of planets, including the Earth, on a flat sheet of paper. A Mercator projection of a hollow transparent sphere could be made by placing a lamp at the centre and a paper cylinder round the sphere. The features on the sphere are drawn on the paper cylinder, which is then cut along a meridian and opened out flat. A great circle becomes a straight line on Mercator's projection. The scale of a Mercator map varies according to latitude, and great distortions arise near the poles.

MERCURY is the closest to the Sun of the nine major planets. It is never a conspicuous object as seen with the naked eye, owing to its relatively small size and to the fact that it can never be seen in a dark sky, far from the Sun. At favourable **elongations** it can, however, be seen shining like a moderately bright star low in the West after sunset or low in the East before sunrise.

ORBIT. Mercury revolves round the Sun at an average distance of 36 million miles. The orbital eccentricity is 0.2056, greater than that of any other major planet apart from Pluto, so that the distance varies from 28.5 million miles (perihelion) to 43.5 million miles (aphelion). The corresponding orbital velocities are 35 and 23 miles per second. The inclination of the orbit is also unusually high, 7°00′14″.0, so that transits of the planet

across the disc of the Sun are infrequent (see **Transits**). The period of revolution is 88 days.

ROTATION. The period of rotation is 88 days, exactly the same as the revolution period. There is no mystery about the apparent coincidence: tidal friction has been responsible for slowing down Mercury's rotation, just as that of the Moon has been slowed by the tidal pull of the Earth (see **Tidal Friction**). For a planet with a circular orbit, this would mean that one hemisphere would experience perpetual day while the other would be in everlasting darkness. Mercury, however, has an orbit that departs appreciably from the circular, so that there is a pronounced libration effect (see **Libration of Moon**). Between the day and night areas there is a fairly wide belt, known as the *twilight zone*, where the Sun rises and sets.

DIMENSIONS AND MASS. Mercury has a diameter of 3,100 miles, so that its volume is 0.06 and its surface area 0.15 of that of the Earth. It is the smallest major planet in the solar system, and is actually inferior in size (though not in mass) to several of the satellites. As it is moonless, its own mass is not easy to determine with accuracy. One recent estimate gives 0.0063 of that of the Earth, in which case the density would be 5.8 times that of water, but others prefer a density value of about 3.8. The escape velocity is 2.6 miles per second, and only a very tenuous atmosphere is to be expected.

SURFACE TEMPERATURE. Mercury is a world of extremes. The centre of the sunlit zone has a perihelion temperature of over 400° C., but since the thin atmosphere is unable to convey any appreciable heat round to the night area, the minimum temperature there must be very low. Temperatures in the twilight zone are of course less unpleasant, but Mercury is clearly a most inhospitable world.

ATMOSPHERE. Until recent years, Mercury was believed to be devoid of any trace of gaseous mantle. In 1950, however, a slight atmosphere with a ground density of about 3/1000 of that of our own was detected. Nothing is definitely known about its composition.

OBSCURATIONS. Antoniadi reported frequent hazy appearances on Mercury, which he described as being commoner and more obliterating than those on Mars. These hazes have not been confirmed by recent studies. Such appearances would indeed be hard to account for; the hypothesis of dust-storms of volcanic origin has little to recommend it, since extensive vulcanism is hardly likely to occur upon a world such as Mercury.

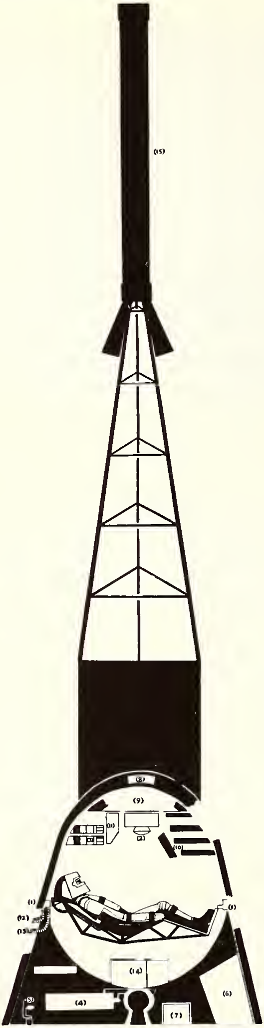
SURFACE FEATURES. Owing to its small size and considerable distance, Mercury is a difficult object to map. The best chart is probably that of Antoniadi. The dark patches are undoubtedly permanent, and the most prominent of them, such as the Solitudo Hermae Trismegisti, may be seen with moderate instruments. Mercury may be mountainous, but as yet there is no definite proof one way or the other. Nor do we know anything about the composition of the surface layers, but it is worth noting that the reflecting power or albedo, 0.07, is exceptionally low.

VISUAL OBSERVATIONS. Like Venus, Mercury shows phases which can be seen with a small telescope (see **Solar System**). Otherwise the planet is of little interest to the amateur astronomer or to the average professional, since the examination of surface detail requires a very large instrument. Mercury is best observed in full daylight, when it is invisible to the naked eye and so cannot be found easily without the aid of a telescope equipped with setting circles.

POSSIBILITY OF LIFE. So far as we can tell, Mercury must be a dead world. It is almost without atmosphere, and water is completely lacking, so that no form of life known to us could survive upon the surface. Even if it can be reached by space-explorers of the future, it seems unlikely that any permanent base will be established there. (P.M.)

MERCURY PROJECT. An American programme for placing manned capsules into orbit round the Earth and recovering them intact.

Seven men were selected and vigorously trained as astronauts. The tests and exercises that were applied to them are described under **Space Medicine.**



A MERCURY CAPSULE. The couch can rotate round the axes of the gimbals (1–1) so that during acceleration and deceleration the pilot is always supported by the moulded cushioning. His behaviour is observed from the ground by means of the TV camera with its wide-angle lens (2) mounted above the couch. The psychological monitoring equipment (3) contains coloured light panels; when a panel is lit up the pilot must respond in a certain manner. A signal corresponding to his action is transmitted to the ground, and in this way his ability to comply with instructions is monitored. The base of the capsule contains the retro-rocket and its tanks (4), the control rockets (5) which prevent tumbling, the parachute system (6) and recovery location devices (7) comprising a transmitter and smoke flares. The heat barrier (8) insulates the capsule from the heat sink above it. Air is reconditioned in the closed circuit breathing ventilating system (9). Other fittings include batteries (10), two-way communications equipment (11), water evaporator line (12), external atmosphere valve (13), fresh water and body waste storage, hand holds by which the pilot can rotate the couch at will during free fall, and portholes. The tripod links the capsule to the emergency rockets (15) which can lift the capsule clear and to a safe height for parachute descent in case of malfunctioning of the carrier vehicle. This rocket and tripod are jettisoned on leaving the atmosphere.

The spaces shown in solid black round the interior of the capsule are filled with crushable material made of a combination of honeycombed plastic and light metal alloys to absorb the shock of a ground landing.

For the initial missions, the pilots are not burdened with elaborate tasks. They are essentially passive passengers, with little control over the vehicle; their chief task is to demonstrate how much can be asked of trained pilots in later missions.

MERCURY PROJECT ASTRONAUTS. These seven young married Americans were selected from a hundred volunteers after a very exhaustive series of tests. They are all regular officers with more than 1,500 hours of jet flying experience. Reading from left to right and downwards, they are: Capt. Donald K. Slayton, U.S.A.F. (36); Lt. Malcolm S. Carpenter, U.S.N. (34); Lt.-Com. Alan B. Shepard Jr., U.S.N. (36); Lt.-Col. Leroy G. Cooper Jr., U.S.A.F. (33); Capt. Vergil I. Grissom, U.S.A.F. (34); Lt.-Col. John H. Glenn Jr., U.S.M. (38); Lt.-Com. Walter M. Schirra Jr., U.S.N. (37).

The capsule was designed after exhaustive research to determine the optimum aerodynamic and physical characteristics for the complex demands of its mission. Cast iron models and dummy capsules were taken to great heights by different carrier rockets and recovered safely.

After the capsule has completed several circuits around the Earth, retarding rockets are fired which cause the capsule to fall out of its orbit in a spiral path. The great heat generated on its re-entry into the atmosphere is partly dissipated by the volatilisation of special surfacing materials, and partly absorbed by the material of the heat sink which is detached a few moments after re-entry. The insulated interior of the capsule is refrigerated.

At a pre-determined altitude a parachute is broken, and normal descent follows. The capsule is built to withstand moderate impact on land or water, and recovery teams are guided to it by signals emitted from the recovery transmitter in the capsule.

MERIDIAN. Any **great circle** passing through the poles of a rotating sphere.

The meridian of a place on the surface of the Earth is the great circle on the celestial sphere passing through the North and South points of the observer's horizon, and through his zenith.

MERIDIAN PASSAGE. The meridian passage or *transit* of a celestial object occurs when the latter crosses the observer's **meridian.** As a body describes its daily circle about the celestial pole it will cross the meridian twice; one transit occurs as it rises to its greatest altitude and is called culmination; the other usually takes place after the object has sunk below the horizon and is therefore unobservable.

Transits are of great importance for accurate time measurements and the determination of positions of stars in the sky. Special telescopes known as *transit circles* are used to record meridian passages. These instruments are

permanently aligned along the observatory's meridian, and optical devices repeatedly move a star's image back by a known amount across the hairline that marks the meridian in the field of view, so that several readings can be taken and averaged at each transit.

MESSIER NUMBER. The number assigned to nebulous objects in the catalogue compiled by the French astronomer Messier. Some of these objects are star clusters, some true nebulae; the catalogue lists 103 objects, and was intended to prevent future confusion between these and comets. The Messier numbers of some well-known objects are:

M 13	Globular Cluster in Hercules.
M 31	Andromeda Galaxy.
M 42	Orion Nebula.
M 57	Ring Nebula in Lyra.

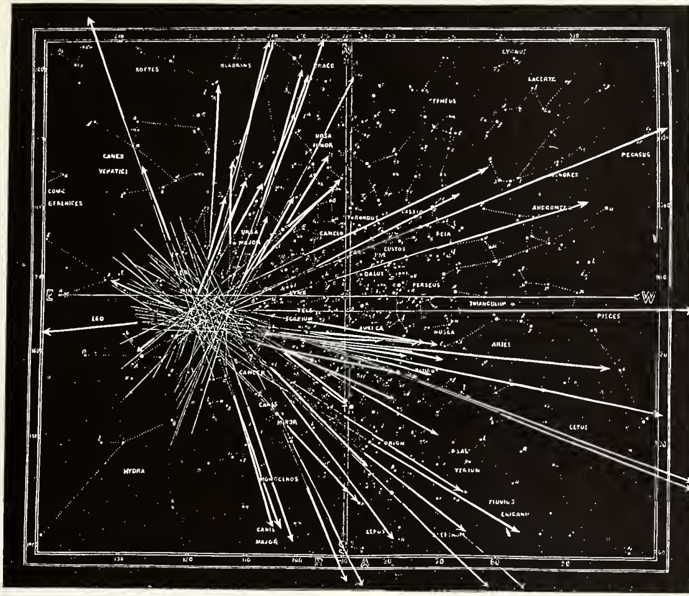
METEOR. Originally any atmospheric phenomenon, such as lightning, but now referring solely to a shooting star. The word is used somewhat loosely, and may connote either the luminous streak of light which can be seen and photographed, the trail of ionized gases which are formed in the process, or the actual solid particle which causes them in its swift passage through the atmosphere. In American practice, the particle is called a *meteoroid*, and it may range in size from the very smallest objects detected by radar methods to the more spectacular bodies which are visible even in daylight. The majority of meteors are completely destroyed in the course of their flight through the atmosphere, but the few that manage to penetrate and to fall on the surface of the Earth are called **meteorites**.

Most meteors are vaporized in less than a second, and this makes visual observation difficult. The larger and brighter meteors may endure for a longer time and have path lengths of hundreds of miles. The brightest of these bodies emit so much light as to cast shadows, and may be visible in full sunlight; such *fireballs* often present a very complex appearance, throwing off sparks and leaving a luminous train which persists after the meteor itself has vanished. The trains are of value in the study of the upper atmosphere, durations of over an hour being not uncommon. Fireballs are sometimes accompanied by noise like thunder – presumably the same effect which accompanies the passage of an aeroplane through the 'sound barrier'. Fireballs which actually explode in flight are termed *bolides*.

The number of meteors to be seen on a moonless night may reach 6 or 8 in the course of an hour's watch; the hourly rate, however, varies with the time of night and the time of year; it is always greater after midnight than before, and in northern latitudes is greater in the autumn and winter months. At certain seasons showers of meteors may reach quite astonishing proportions, with an hourly rate of many thousands. Such great storms of meteors have occurred in 1833, 1866, 1872, 1885 and 1933. The meteors which are seen by one observer during a shower may be in any part of the sky, but their lines of flight when produced backwards, intersect in a small area known as the *radiant* of the shower. Radiants are named from the constellation in which they appear; thus the Leonid meteors of November appear to radiate from Leo, the August Perseids from Perseus, etc. In a few cases the name is taken from an associated **comet**; thus the Andromedids are often called Bielids (after **Biela's Comet**) and the October Draconids are the Giacobinids.

The astronomical significance of meteors was not appreciated until the great Leonid shower of 1833, November 12–13. On that night America witnessed a storm of meteors lasting nine hours, during which the shooting stars fell as thickly as snowflakes, reaching at one period an estimated hourly rate of 35,000. With so many meteors visible at one time, the fact that they all appeared to radiate from a point in Leo was obvious. The effect was shown to be one of perspective, the meteors actually travelling in parallel paths which appear to vanish at a point, as in the more familiar case of railway lines. During the next few years it became clear that there were well-defined showers on the same date each year, and this led to the theory that the meteoric dust was distributed in orbits intersecting the Earth's. Each year a shower is seen as the Earth passes the point of intersection. In many cases the dust is not uniformly distributed in the orbit.

Research showed that the Leonids had been recorded as far back as A.D. 902, and tended to recur at intervals of 33 years. Another shower was therefore predicted for 1866. In that year a fine shower of Leonids was seen

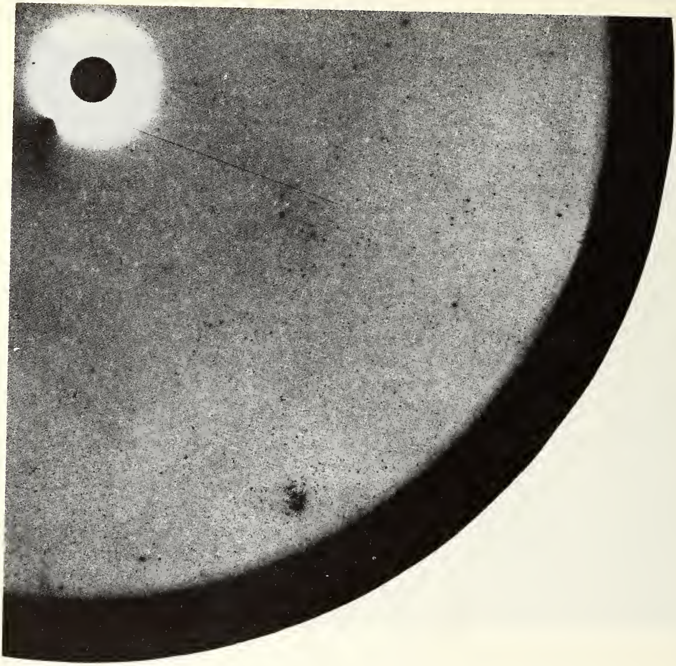


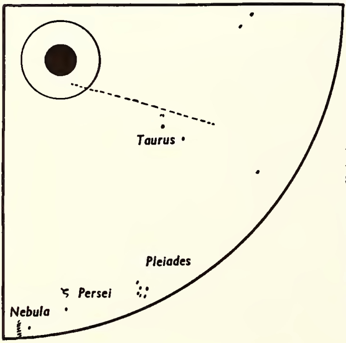
THE LEONID RADIANT. The thick white lines represent the observed trails of meteors drawn on a star map. The thin white lines produce these trails backwards; all but a few intersect with the others in a small region, the *radiant* of the Leonid meteor shower. The remaining trails are those of sporadic meteors. Very compact meteor streams have sharply defined radiants.

mainly in Europe, although it was not so spectacular as that of 1833. There was no repetition of this event in 1899, probably because perturbations by Jupiter and other planets had changed the orbit.

The close connection between comets and meteors was first revealed by the similarity of the orbits of the Perseid meteors and the comet of 1862. This was quickly followed by the identification of the Leonids with Tempel's Comet of 1866, of the Lyrids with the comet of 1861, and of the Andromedids with Biela's Comet.

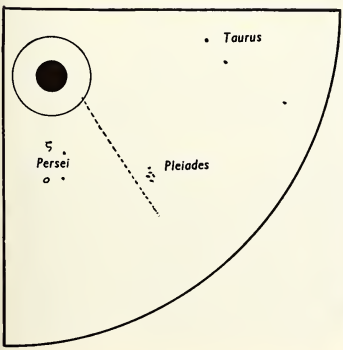
PHOTOGRAPHIC METHODS. The chance passage of a bright meteor across the field of view of an astronomical camera has occasionally resulted in a record of interest, and a valuable collection of plates is preserved at Harvard. Systematic attempts to photograph meteors began at Yale in 1891, a number of cameras being attached to equatorial mountings at each of two stations, the exposure being interrupted by a rotating sector placed in front of the lens. The base line was far too short (about two miles) to give accurate results, but the method is one on which all subsequent work has been based. In 1932 further experiments began at Harvard and by 1936 Whipple was using cameras there and at Oak Ridge (Mass.), the base line in this case being 24 miles. The more rapid emulsions which were then available gave better results, but the number of successful duplicate plates



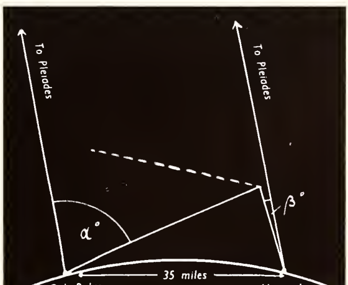


A pair of double station meteor photographs. Astronomers prefer to work on the negatives such as the ones shown here, because they reveal finer detail. Each trail is broken up by the rotating shutter (see following page). The large white circle with the black centre arises through the technique used in the special wide-angle cameras and may be disregarded. Each station sees the trail against a different part of the star background, and from this difference the exact location of the trail may be calculated in a manner based on ordinary triangulation.

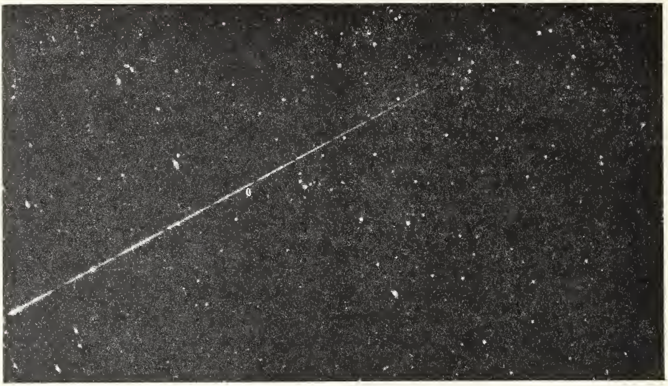
(*Harvard University Observatory*)



Taurus
ζ
Persei
o
Pleiades



To Pleiades
To Pleiades
α°
β°
35 miles
Oak Ridge
Harvard



Part of a meteor trail photographed through a rotating shutter which cuts off the light at regular intervals. The number of breaks along the whole trail can be used to calculate the time taken by the meteor to traverse it; changes in the meteor's speed show up as changes in the length of successive 'dashes'; the heating effects due to friction with the atmosphere lead to fluctuations of brightness. A pair of such photographs taken from two separate stations yields information not only about the meteor itself and its path, but about the temperature and pressure of the atmospheric layers in which it has burnt itself up. *(Harvard University Observatory)*

was still disappointingly small. Only the very brightest meteors gave any impression at all, and on the average only one meteor in 100 hours' exposure time could be expected. In 1946 plans were made for a more efficient camera, and these led to the Super-Schmidt cameras which are now in use. (See **Schmidt Camera**.)

Exposures of ten minutes are used, and the cameras are capable of photographing meteors almost to the limit of naked eye brightness. A rotating shutter, which causes breaks in the trail of the meteor at intervals of 1/60 of a second, is placed just in front of the photographic film. It is estimated that the length of path can be determined to within a few feet and the velocity to one part in a thousand, while the actual retardation of the meteor in the atmosphere can be measured on some of the longer trails at several points in the path. The results obtained cannot compete in numbers with those from radar methods (see **Radio Astronomy**), but they afford the most accurate means yet devised for height and orbit determination.

HEIGHTS. In general, meteors appear and disappear at heights which lie in the range 70 to 120 kms. above the Earth's surface, but the individual values vary. The faster meteors begin and end at the greater heights.

NUMBERS AND MASSES. The general hourly rate of 6 or 8 is due partly to a number of minor showers, but in the main to sporadic meteors. Although this rate appears small, it is merely the number seen by an observer with a limited range of vision over a very small fraction of the Earth's surface. The total number of meteors that enter the atmosphere in the course of one day is estimated at about 100 millions. Much larger

values are obtained when the fainter telescopic or radio-echo meteors are included.

In spite of such large numbers, the actual mass of meteoric material entering the Earth's atmosphere each day is not considered to be greater than a few tons. The individual meteor is *very small*, and the ordinary shooting star may be regarded as a grain of dust often weighing as little as a thousandth of a gram. The brighter meteors and fireballs may reach 100 to 500 grams, but there is no upper limit, since masses of many tons are known to have fallen as meteorites. There is, however, a lower limit, since the very smallest particles, like the very largest, cannot be vaporized and will fall to the Earth as **micrometeorites.** The average density of the meteoric dust in the solar system is probably of the same order as the density of matter in interstellar space.

Calculations indicate that meteoric matter is extremely light, porous and friable, and is so weak that the smallest force is enough to shatter it. The smaller bodies are thus destroyed at once, or scattered into hundreds of minute particles which are instantly rendered luminous. The result is of great interest in connection with Whipple's theory of the structure of comets, and of the formation of interplanetary dust.

MAGNITUDES. In general, the brighter meteors begin at a greater height and end at a lower height than the faint ones. The following values are averages for groups of Perseids:

Effect of Height on Magnitude.

Mag.	−3.4	−1.1	+1.8	+3.4
Begin	116	115	112	109 kms.
End	87	95	99	98 kms.

SPECTRA. There are two distinct classes of meteor spectra, which differ mainly in the strength of the calcium lines, and since the spectrum consists of lines (superposed on a continuous background) it must originate from material in the vapour state. The lines of sodium and magnesium are often seen, and when magnesium is present the light of the meteor is predominantly green. Other elements detected include nitrogen (almost certainly atmospheric), hydrogen, oxygen, aluminium, silicon, chromium, manganese, iron and nickel – all found in meteorites.

TRUE AND APPARENT RADIANTS. The marked variation in the number of meteors seen at different times depends on the fact that the observed radiant is not the actual direction in space from which the meteors are travelling, but is only the *apparent* direction resulting from the combination of the motions of the meteors and of the Earth. The effect is exactly that of rain falling on the window of a moving train. Even if the rain is falling vertically, its trace on the window is slanting, the direction from which it appears to come being displaced in the direction of motion of the train, whose speed determines the amount of change. Similarly, the apparent meteor radiant is displaced towards the *apex of the Earth's way*, the point on the celestial sphere towards which the Earth is for the moment travelling. The apex comes into view on the eastern horizon of an observer at local midnight, and is due South at about 6 a.m., and this accounts for the fact that more meteors are to be seen during these hours. Moreover, since the apex lies on the **ecliptic**, there will be more meteors visible on autumn mornings, when the ecliptic rises to its greatest altitude above the eastern horizon (in northern latitudes).

VELOCITIES. The velocities of meteors range from about 12 to 72 km/sec., but until recent years such figures depended solely on theoretical values. In the photographic method, the breaks in the trail caused by the rotating shutter represent time intervals of 1/60 of a second; if the height of the meteor is known (from duplicate photographs) the velocity may be determined with great accuracy.

ORBITS. The position of the true radiant in the sky gives the actual direction in space from which the meteor is coming; this direction is a tangent to the **orbit** at the time of the observation. If the velocity of the meteor is also known it is possible to determine all six elements of the orbit. The calculation of the orbit of a meteor stream is somewhat complicated, but much of the work can now be done on electronic computing machines. The results that have been obtained for the major showers agree well with the orbits of comets known to be associated with them, but work on minor showers has provided a number of surprises.

SHOWERS. Details of the major *meteor showers* are given in the table, which includes the names of the comets which are associated with these meteor streams. In the past, and in all cases in which a determination of velocity is not practicable, these associations have been based on four important criteria: (1) the orbits must, of course, be similar. (2) The meteor shower may give periodic displays, as in the case of the Leonids and Giacobinids. (3) If the meteor stream is of sufficient width, the display may last for several days, but in such cases the radiant shows a definite motion; thus the Perseid radiant moves from 27°, + 53° to 54°, + 58° in the period July 27 to August 17. (4) Planetary perturbations affect the date of the shower.

None of the major showers gives complete agreement on all four points, but the balance of evidence is in favour of these associations. In other cases, some discrimination must be used. For example, the δ-Aquarids and Orionids may be associated with Halley's Comet, since there is some resemblance between the orbits, but Halley's Comet does not come closer to the Earth than 0.15 astronomical units. This does not preclude the comet from having a common origin with the two showers in the remote past, since perturbations over a long period may have caused serious changes in the orbit. Such changes must once have taken place in the orbit of Encke's Comet, and the ejection of matter from the head of the comet, particularly at two epochs 1,500 and 4,700 years ago, would account satisfactorily for the occurrence of the Taurids and ζ-Perseids of to-day.

SPORADIC METEORS. Much of the early work on meteors was concerned with mere numbers, and particularly with the variation of hourly rate. Statistical analysis pointed to a high proportion of hyperbolic orbits, but to-day all approaches lead to the opposite conclusion – that there is no evidence whatever for a preponderance of hyperbolic velocities among meteors. In 300 photographs, reduced in duplicate, Whipple has found no case of hyperbolic motion, all the measured velocities being below the parabolic limit. The radio-echo results are similar, although less accurate; here a small percentage of meteors appear to have velocities slightly in excess of parabolic. It is reasonable to suppose that this represents merely the spread of the errors of measurement.

STRUCTURE OF METEOR STREAMS. The width of a stream of meteoric dust is always very small. For instance, the Perseid shower, which may last for about 18 days, has a width of only 0.075 astronomical units.

Within this stream the particles must be widely separated. Even in a great shower such as the 1833 return of the Leonids, when the hourly rate was about 4,000 times the normal, the particles must have been at distances of the order of 15 km. Thus the dust particles will each have a separate existence, and the stream will consist of a tangled array of individual paths. The old idea of a uniform structure – the 'bicycle tube' theory – is wrong; planetary perturbations alone would disrupt such a structure, and other forces are present which also have a disturbing influence on small particles.

Perturbing forces, however, must last for some time to be effective, and the persistence of such showers as the Perseids, Leonids and Lyrids over many centuries must be due to the fact that they have escaped prolonged disturbance. The Lyrids have an orbit which is inclined at 80° to the ecliptic, while the Perseids and Leonids travel in retrograde orbits, so that they move in the opposite direction to Jupiter, whose influence is therefore short-lived.

Planetary perturbations affect each particle individually, and so the orbits in which the particles travel can never be identical with that of the parent comet, and there are, in fact, difficulties in accepting the view that all meteors are the débris of comets. The Perseids and Leonids have been visible for centuries, yet the comets with which they are associated were only discovered in the 1860s. Although comets can come within 0.05 astronomical units of the Earth, and 60 within 0.1 units, the only accordance with meteor showers are the eight given in the table. As these can give showers, it is surprising that the others do not.

Meteoric dust travelling in a comet's orbit does not prove the dust to be the débris of the comet. In the most recently formed shower, that of the Giacobinids, the material of the shower of 1926 was *in front* of the comet.

METEOR SHOWERS

Name	Duration	Maxi-mum	Radiant	Hourly Rate	Velo-city km/sec.	Associated comet
NIGHT TIME SHOWERS:						
Quadrantids . . .	Jan. 3	Jan. 3	231°+50°	40	41	
Lyrids	Apr. 20–22	Apr. 21	270°+33°	8	48	1861 I
δ-Aquarids	May 1–11	May 5	337°— 1°	12	66	Halley?
June Draconids . .	June 28	June 28	208°+54°	12		Pons-Winnecke
η-Aquarids	July 24–Aug. 6	July 30	340°—15°	20	41	
Perseids	July 27–Aug. 17	Aug. 12	46°+58°	50	61	1862 III
October Draconids .	Oct. 9	Oct. 9	262°+54°		23	Giacobini-Zinner
Orionids	Oct. 15–25	Oct. 20	94°+16°	16	66	Halley ?
Taurids	Oct. 26–Nov. 16	Oct. 31	52°+21°	6	31	Encke
Andromedids . . .	Nov. 14	Nov. 14	23°+44°	?	16	Biela
Leonids	Nov. 15–20	Nov. 16	152°+22°	6	72	1866 I
Geminids	Dec. 9–13	Dec. 12	113°+32°	60	35	
Ursids	Dec. 21–22	Dec. 22	206°+80°	12	35	1939 X
DAYTIME SHOWERS:						
o-Cetids	May 13–23	May 15	30°— 3°	15	37	
ζ-Perseids	June 1–16	June 8	59°+22°	40	29	Encke
Arietids	May 30–June 18	June 8	44°+23°	60	38	
β-Taurids	June 25–July 7	June 29	85°+17°	24	31	Encke

But families of comets are known which have similar orbits. This would seem to be a parallel case, and it appears unwise to depart from the simple view that *meteors and comets have a common origin.*

METEORS AND THE UPPER ATMOSPHERE. The presence of high wind-speeds has been shown repeatedly in the past by the behaviour of visual meteor trails, which frequently become greatly distorted in the course of a few minutes. Radio-echo methods show the presence, in the 80–100 km range, of a prevailing wind, of about 30 m.p.h., blowing to the East in summer and winter, and to the West in spring and autumn; in addition there is a wind of 40 m.p.h. whose direction rotates clockwise twice during the day. Similar results have been found in the southern hemisphere, but the rotation is anti-clockwise. These directions appear to be reversed at lower levels, and ionospheric measurements at higher levels show a similar semi-diurnal change, but this occurs about 3 hours earlier. The winds are, in fact, highly stratified and variable.

The onset and fluctuation in the incandescence of meteors have been used to assess atmospheric temperatures at different heights, and the results are in agreement with corresponding data from rockets and artificial satellites.

METEORS AND THE LUNAR SURFACE. The enormous size of some of the lunar craters makes it obvious that each must have originated in some form of violent explosion. The suggestion of a meteoric origin is not new, but has received considerable support in recent years, especially among those who are not experienced in observing the Moon in a large telescope. It is assumed that in the remote past the Earth and Moon were subject to intense bombardment from large meteors. Craters formed in this way on the Moon would be larger than those on the Earth, which has a protective atmosphere; and the lunar craters, moreover, would not

METEORITE CRATERS that have become filled by erosion. These giant scars, some measuring 10,000 feet across, were caused by a shower of meteors, and pit an area 80 miles wide from Virginia to Georgia, U.S.A. (*Fairchild Aerial Surveys*)

be exposed to atmospheric erosion. The impact of a large body on the Moon's surface would be so great that the energy liberated would be comparable with that of a hydrogen bomb. On this theory, the craters are just like bomb-craters, and the flat floors of the craters are merely settled dust, caused by the crumbling of the rocks as they are alternately baked in the heat of the Sun and frozen at night.

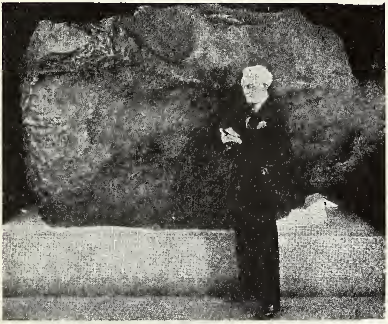
The older volcanic theory, in spite of its weaknesses, still receives support from observers. They point out that the craters are not distributed at random, as they would be on the meteoric theory, but occur in pairs, lines and overlapping chains, and even some of the great walled plains occur in lines. This might happen along lines of weakness of the crust. The level floors are easily explained as solidified lava, and a crater such as *Wargentin*, filled to the brim, which is many hundreds of feet above the surrounding plain, appears to have been formed by the flow of lava underneath. Summit craterlets are found on the tops of mountains, of isolated hills and the central peaks of craters. These small formations occur in considerable numbers, and the probability that meteors could make precisely central impacts on such a number of peaks is almost zero. The subject continues to form a fruitful source of speculation, but it is impossible at present to decide between the rival theories. (See also **Moon.**)

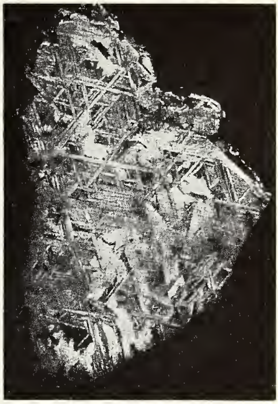
After a century of very slow progress, it seems likely that meteoric astronomy is at last assuming its true importance, as a probe of the upper atmosphere and of interplanetary space. (J.G.P.)

METEORITES are solid bodies which have entered the atmosphere from outer space and struck the Earth's surface, either as a single mass or, more frequently, as a shower of small pieces scattered over a wide area. Meteorites are too large to be vaporized completely in the air like **meteors.** There are three broad classes of meteorites: (a) the *irons*, which are always associated with a certain amount of nickel, and which, on being etched and polished, show the curious Widmanstaetten figures, (b) the *stones*, which are mainly silicates, and (c) the *stony-irons*, which have a spongy structure of iron-nickel mixed with silicate minerals. The greater proportion of meteorites found on the Earth are irons (66%); stones account for 26%.

The largest meteorite ever seen to fall weighed 820 lbs. (Arkansas, U.S.A., 1930); the largest one known weighs 60 tons, and it remains, buried with its top on a level with the surface, at Hoba West in South Africa. This, like most large meteorites, is an iron. Larger falls than this have certainly occurred, but it would appear that in such cases the body disintegrated. In the Arizona Desert, about 35 miles east of Flagstaff, there stands a single hill in what is otherwise a flat plain. At the centre of this hill is a crater three-quarters of a mile across and 600 feet deep, its rim being 140 feet above the surrounding plain. This is *Meteor Crater*, and is believed to have been caused by the fall of a meteorite some thousands of years ago.

Actual falls of this order of size have been reported during the present century, the two most important being in Siberia. On 30th June, 1908, a great collection of stones estimated to weigh some thousands of tons landed in the desolate region of the river Yenesei. Expeditions found great areas of the

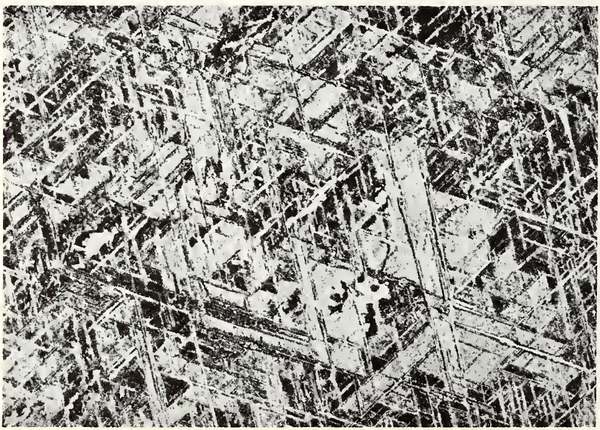




Upper left: the 'Ahnighito' Meteorite in the Hayden Planetarium.

Upper right: an etched section of the Knowles iron meteorite, showing the characteristic Widmanstaetten figures.

Lower left: a large iron meteorite. Very few meteorites weighing more than a ton are stony.



Above: part of the trail of a 'fireball'. *Below:* Widmanstaetten figures on the etched and polished section of an iron meteorite.

forest laid waste for twenty miles around the scene, the trees lying with their tops all pointing outwards from the centre, and completely bare, as if they had been burned. At the time of the fall a column of fire appeared over the forest, while the noise of the impact was heard as a crash with several thunderclaps, more than 600 miles away.

A more recent event was the fall of stones in a dense forest in eastern U.S.S.R. on February 12th, 1947. On this occasion the actual fireball was seen in flight. Using all the resources of modern expeditions (aeroplanes, mine-detectors, etc.) various parties were able to find many craters, and succeeded in collecting more than 30 tons of nickel-iron meteorites.

The largest single crater which has been associated with such a fall is Chubb Crater in Ungava; this is about 3 miles across and almost perfectly round, with walls at an angle of 45°.

The origin of meteorites would appear to be different from that of meteors. Whereas the latter are known to be associated in most cases with comets, meteorites show a much closer relationship to the asteroids. They fall mostly in daylight hours, and their orbits are of the same type as those of the asteroids. The larger meteorites probably originated in the disruption of one or more of these planetary bodies, whose massive metallic cores and stony shells provide the material which falls upon the Earth. (J.G.P.)

METHANE (CH_4) or 'marsh gas' occurs in the atmospheres of the giant planets. Its molecule contains one atom of carbon and four of hydrogen. Methane condenses to a liquid at $-160°$ C. at atmospheric pressure.

MICROMETEORITES are the smallest particles which fall to the Earth from outer space; they are microscopic in size and, unlike meteors, are too small to become incandescent in their passage through the atmosphere. Particles of four thousandths of a millimetre (four microns) diameter will not be melted at a velocity of 25 km/sec., and the upper limit of size of these bodies may be taken to be less than 100 microns. The number of particles of these dimensions which fall on the Earth has been estimated at about 10,000 times the figure which is inferred from the statistics of meteors. Hence only a small fraction of these particles can be vaporized during their fall through the atmosphere.

Dust collected from arctic snow and other sources contains microscopic black spheres, which are magnetic and range in size from 5 to 30 microns in diameter. It has not been definitely proved that these bodies are meteoric and do not arise from industrial furnaces; such fine dust can drift many thousands of miles in the upper atmosphere. Similarly the high nickel content of deep-sea ooze, which has been attributed to meteoric dust, has received other explanations, but this material also contains black magnetic

An aerial view of the meteorite crater in Arizona. Its size may be judged from the roads leading up to it.

(*Fairchild Aerial Surveys*)

spheres, although these are larger and differ in other ways from the fine dust of the atmosphere. Experiments with high altitude rockets have shown that impacts with small particles occur at a frequency which is at least consistent with a figure of a thousand tons of meteoric dust per day over the whole Earth. Any inconsistency that may remain between the measured figures and the theoretical estimates may eventually be explained by the unexpectedly small densities of meteoric material (see **Meteor**). (J.G.P.)

MINITRACK. A system for tracking a rocket or artificial satellite by means of radio waves transmitted from the vehicle itself. Several ground stations are required.

MINOR PLANETS. See **Asteroids**.

MINUTEMAN. A U.S. airforce **missile** of variable range designed to replace the *Atlas* and *Titan* missiles.

MIRROR. In reflecting **telescopes**, the image is formed by a concave mirror of parabolic cross-section. These mirrors are silvered, or coated with aluminium, on the front surface, in contrast to ordinary looking-glasses. The light does not therefore have to enter the material of the mirror at all, and glass of the highest optical quality, essential for lenses, is unnecessary. Although glass is usual, opaque materials could be used, since they only act as supports for the real mirror which is the silver or aluminium film. A special alloy, speculum metal, was formerly employed without any coating, but it tarnished and had to be re-polished periodically – a very delicate task, since the surface has to be brought to the correct curve or *figure* anew each time. With a glass-based mirror, the metal film can be replaced as often as necessary without prejudice to the figure of the glass.

MISSILE. An unmanned rocket vehicle that can be 'sent' to a definite target or location. A *ballistic missile* is guided only until its rocket motors have ceased firing; from then on it follows a fixed trajectory in free fall as does an artillery shell. On the other hand, the course of a **guided missile** may be changed in flight by instruments within the projectile linked to the propulsion units, by radio signals from the ground, by a homing device or by a combination of these systems.

Missiles are further classified according to range, *e.g.* intermediate-range ballistic missile (I.R.B.M.), and their mode of use, *e.g.* surface-to-air missile (S.A.M.).

Most current missiles are propelled by liquid fuels and oxidants for the greater part of their powered flight, but solid propellents are returning into favour because of their simplicity and ease in handling. (See **Rocketry**.)

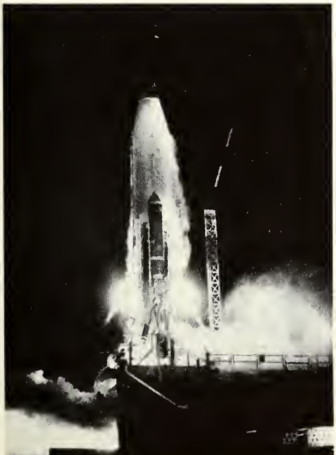
Existing missiles serve a variety of purposes. Some are designed to carry atomic or nuclear bombs; others to take the place of artillery and anti-aircraft guns in tactical engagements, or to intercept other missiles (the anti-missile missile); further applications include the confusion of enemy early warning installations, radio relay, and the launching of scientific probes and satellites.

The chief incentive for missile development has always been a military one, and the rapid advance of space technology is a direct and positive outcome of warlike needs. To some extent this continues to be true of the gigantic space exploration missiles that are now being evolved, such as *Nova*, which is 220 ft. high, weighs 6,700,000 lb. at take-off and has a 9 million pound thrust. It is a five-stage vehicle, the fifth being reserved for the return journey from the Moon.

A comparative table of missiles is given on pp. 174–5.

MIZAR (*ζ-Ursae Majoris*) is one of the seven bright stars in the Plough. Very close to it is **Alcor**. A small telescope reveals that Mizar has two components, one of which is itself a spectroscopic **binary star**.

Opposite right: VIKING 12, one of a series of missiles developed from the German V–2 after World War II. *Upper left:* JUNO II lifting with the space probe PIONEER IV mounted. *Lower left:* firing of an ATLAS missile.

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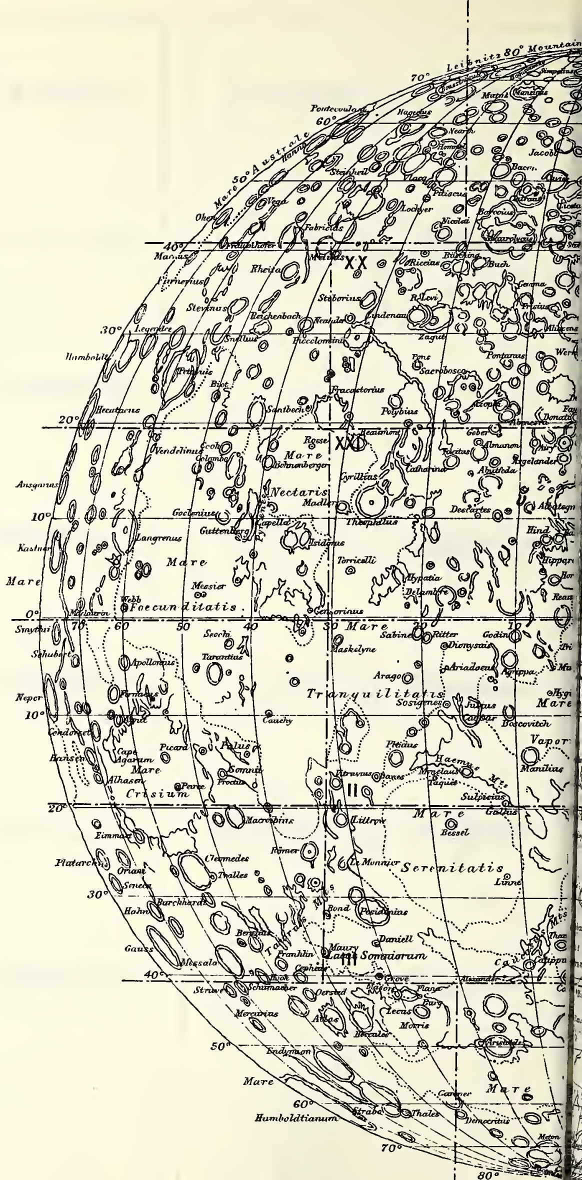
DATA	Atlas (U.S.A.)	Black Knight (U.K.)	Bomarc (U.S.A.)	Blue Streak (U.K.)	Comet 2 (CH-18) (U.S.S.R.)	Golem 2 (U.S.S.R.)	Goose (U.S.A.)
							
Type	I.C.B.M.	I.R.B.M.	Surface-to-air	I.C.B.M.	I.R.B.M.	Sub.-to-surface	Various
Length (*ft.*)	85	36	—	70	—	—	—
Take-off Wt. (*lbs.*)	243,000	—	16,000	—	41,500	—	—
Number of Stages	3	1 or 2	2 (ramjets, booster)		1	—	2
Propellents	Liquid oxygen, kerosene	1, peroxide-kerosine; 2, solid	1, solid; 2, liquid	Liquid	Solid	Alcohol, nitric acid	1, solid; 2, turbojet
Thrust of 1st Stage (*lbs.*)	400,000	—	12,000	—	99,000	—	100,000
Max. Range (*miles*)	6,500	500 (vertical)	250	over 2,000	630	1,250	over 2,000
Guidance	Inertial	Autopilot and command	radar-homing	Inertial and control	Inertial	Radio-inertial	Inertial
Remarks	Used in project SCORE, To be replaced by Minuteman	Re-entry research	—	Launched from under-ground	Thrust/weight = 2.4	Launched from under water	—

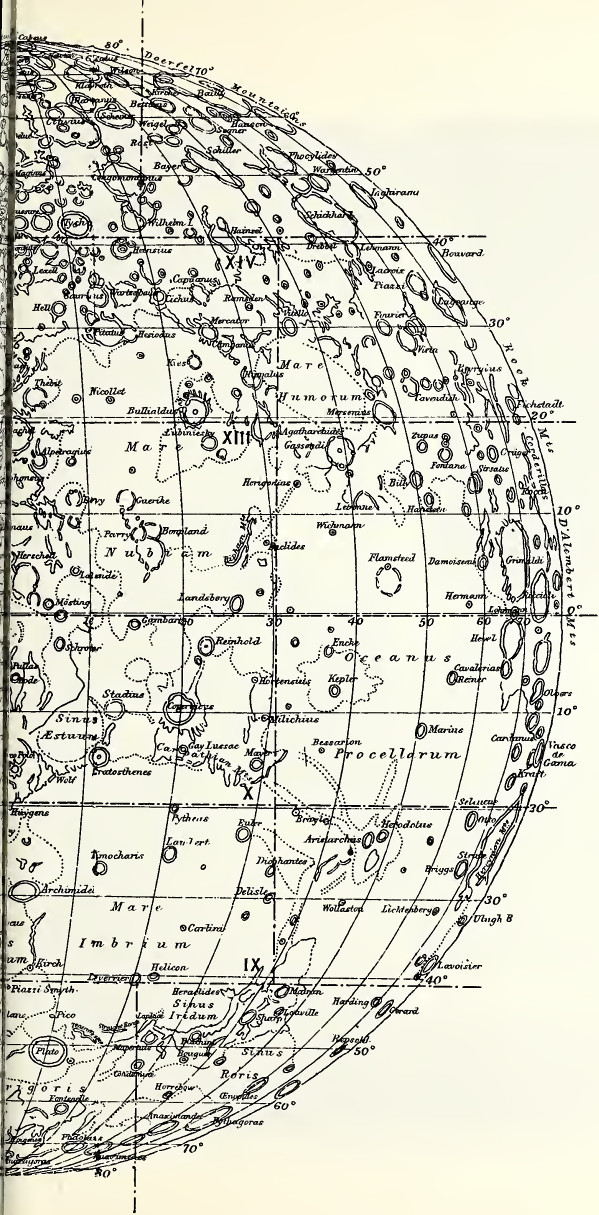
DATA	Juno II (U.S.A.)	Jupiter (U.S.A.)	Jupiter-C (U.S.A.)	Matador (U.S.A.)	Minuteman (U.S.A.)	Nike-Hercules (U.S.A.)	Polaris (U.S.A.)
							
Type	Satellite launcher	I.R.B.M.	Satellite launcher	I.R.B.M.	I.C.B.M.	Surface-to-air	I.R.B.M.
Length (*ft.*)	76	58	70	—	—	—	—
Take-off Wt. (*lbs.*)	134,500	105,000	64,000	12,000	—	—	28,000
Number of Stages	4	1	4	2 (booster, turbojet)	3	2	2
Propellents	1, oxygen-kerosene; 2, 3, 4, solid	Oxygen, kerosene	Oxygen, hydrazine and solids	Solid	Solid	Solid	Solid
Thrust of 1st Stage (*lbs.*)	165,000	150,000	75,000	52,000	—	—	80–100,000
Max. Range (*miles*)	—	1,500	3,000	700	5,750	75	1,500
Guidance	—	Inertial	—	Radar	—	Command	Inertial
Remarks	Launched Pioneer IV	—	—	Obsolescent	First launched October, 1959	—	Launched from under water

DATA	Regulus II (U.S.A.)	Snark (U.S.A.)	T-2 (M 103) (U.S.S.R.)	T-3 (M 104) (U.S.S.R.)	T-3a (U.S.S.R.)	T-4 (M 102) (U.S.S.R.)	T-4a (U.S.S.R.)
							
TYPE	I.R.B.M.	I.C.B.M.	I.R.B.M.	I.C.B.M.	I.C.B.M.	I.R.B.M.	I.C.B.M.
LENGTH (*ft.*)	—	—	100–125	110–160	—	—	—
TAKE-OFF WT. (*lbs.*)	22,000 (minus booster)	50,000	180,000	230,000	185,000	71,000	232,000
NUMBER OF STAGES	2 (booster and jet)	2 (booster and jet)	2	2	2	2	—
PROPELLENTS	1, solid; 2, jet-fuel	1, solid; 2, jet-fuel	Oxygen, alcohol	Oxygen, kerosene	Oxygen, kerosene	Oxygen, hydrazine	—
THRUST OF 1ST STAGE (*lbs.*)	15,000	66,000	254,000	270,000	270,000	—	—
MAX. RANGE (*miles*)	1,000	5,500	1,800	5,000	6,200	1,000	12,000
GUIDANCE	Command or inertial	Stellar inertial	Radio-inertial	Radio-inertial	Radio-inertial	Radio-inertial	—
REMARKS	May be launched from submarines	Boost-glide vehicle	—	—	—	—	Boost-glide, may be manned

DATA	T-6 (U.S.S.R.)	T-7 (U.S.S.R.)	Thor (U.S.A.)	Thor-Able (U.S.A.)	Titan (U.S.A.)	Vanguard (U.S.A.)	Viking (U.S.A.)
							
TYPE	Surface-to-air	Surface-to-air	I.R.B.M.	Satellite launcher	I.C.B.M.	Satellite launcher	Research
LENGTH (*ft.*)	—	—	65	90	—	72	41.5
TAKE-OFF WT. (*lbs.*)	4,000	5,050	100,000	104,500	222,000	22,600	10,000
NUMBER OF STAGES	2 (booster, jet)	—	1	4	2	3	—
PROPELLENTS	1, solid	oxygen, hydrazine	oxygen, kerosene	1, 2, as Thor; 3, 4, solid	Oxygen, JP-6	1, oxygen, petrol; 2, hydrazine, nitric acid; 3, solid	Oxygen, alcohol
THRUST OF 1ST STAGE (*lbs.*)	10,000	11,000	150,000	150,000	300,000	30,000	20,500
MAX. RANGE (*miles*)	—	—	2,000	5,500	5,500	—	158 (vertical)
GUIDANCE	Radar	Inertial	Inertial	—	Radio-inertial	—	—
REMARKS	Ceiling 60,000 ft. Proximity fuse	Ceiling 60 miles	To be replaced by Minuteman	Launched Pioneer I and V	—	Launched Vanguard satellites	—



Leibnitz 80° Mountains
Mare Australe
Pontecoulant
Hagecius
Hanno
Steinheil
Vlacq
Pitiscus
Lockyer
Nicolai
Barocius
Maurolycus
Jacobi
Oken
Vega
Fabricius
Fraunhofer
Marinus
Metius
Riccius
Büsching
Buch
Rheita
Furnerius
Stiborius
R. Levi
Stevinus
Reichenbach
Neander
Lindenau
Zagut
Legendre
Snellius
Piccolomini
Humboldt
Petavius
Biot
Pons
Sacrobosco
Pontanus
Fracastorius
Santbech
Polybius
Azophi
Hecataeus
Vendelinus
Cook
Colombo
Rosse
Mare Nectaris
Bohnenberger
Beaumont
Geber
Almanon
Airy
Argelander
Catharina
Abulfeda
Cyrillus
Ansgarius
Madler
Theophilus
Descartes
Goclenius
Guttenberg
Capella
Isidorus
Hind
Hipparchus
Kastner
Langrenus
Mare Foecunditatis
Torricelli
Hypatia
Delambre
Messier
Webb
Maclaurin
Censorinus
Smythii
Secchi
Taruntius
Mare Tranquillitatis
Maskelyne
Sabine
Ritter
Dionysius
Godin
Ariadaeus
Agrippa
Schubert
Apollonius
Arago
Sosigenes
Julius Caesar
Neper
Firmicus
Auzout
Condorcet
Cauchy
Boscovitch
Manilius
Hansen
Cape Agarum
Picard
Palus Somnii
Proclus
Peirce
Mare Crisium
Alhazen
Plinius
Haemus Mts
Menelaus
Taquet
Vitruvius
Dawes
Sulpicius Gallus
Mare Serenitatis
Bessel
Littrow
Macrobius
Eimmart
Römer
Plutarch
Oriani
Seneca
Cleomedes
Tralles
Le Monnier
Linne
Burckhardt
Hahn
Bond
Posidonius
Taurus Mts
Berzelius
Gauss
Messala
Franklin
Maury
Daniell
Lacus Somniorum
Cepheus
Caucasus Mts
Struve
Schumacher
Oersted
Grove
Mason
Plana
Alexander
Mercurius
Atlas
Hercules
Burg
Lacus
Morris
Endymion
Aristoteles
Mare Humboldtianum
Strabo
Thales
Gartner
Democritus
Mare
Meton


Doerfel Mountains
Clavius
Blancanus
Scheiner
Klaproth
Wilson
Kircher
Bailly
Bettinus
Weigel
Segner
Hausen
Rost
Schiller
Phocylides
Bayer
Wargentin
Longomontanus
Inghirami
Tycho
Wilhelm I
Schickhard
Hainzel
Heinsius
Drebbel
Lehmann
Bouvard
Lexell
XIV
Capuanus
Lacroix
Piazzi
Hell
Wurzelbauer
Cichus
Ramsden
Lagrange
Mercator
Vitello
Fourier
Pitatus
Hesiodus
Campanus
Vieta
Rook
Kies
Mare
Byrgius
Thebit
Hippalus
Humorum
Nicollet
Cavendish
Eichstadt
Bullialdus
Mersenius
Lubiniezky
XIII
Agatharchides
Gassendi
Alpetragius
Zupus
Cordillera Mts
Fontana
Crüger
Sirsalis
Herigonius
Billy
Guerike
Letronne
Hansteen
Rocca
Parry
Bonpland
Wichmann
D'Alembert Mts
Nubium
Riphaeus Mts
Euclides
Flamsteed
Damoiseau
Grimaldi
Herschel
Lalande
Landsberg
Hermann
Riccioli
Mösting
Lohrmann
Gambart
Hevel
Reinhold
Encke
Schröter
Oceanus
Cavalerius
Reiner
Pallas
Hortensius
Kepler
Olbers
Stadius
Copernicus
Sinus
Æstuum
Milichius
Marius
Cardanus
Vasco de Gama
Gay Lussac
Carpathian Mts
Bessarion
Procellarum
Mayer
Eratosthenes
Kraft
Wolf
X
Seleucus
Huygens
Pytheas
Euler
Brayley
Herodotus
Otto
Lambert
Aristarchus
Timocharis
Diophantes
Struve
Briggs
Hercynian Mts
Archimedes
Delisle
Mare
Wollaston
Lichtenberg
Ulugh B
Carlini
Imbrium
Kirch
IX
Lavoisier
Helicon
Leverrier
Piazzi Smyth
Heraclides
Maupertuis
Harding
Gerard
Sinus Iridum
Pico
Laplace
Sharp
Louville
Plato
Bouguer
Sinus
Repsold
Roris
Condamine
Horrebow
Œnopides
Fontenelle
Anaximander
Pythagoras
Philolaus
80°
70°
60°
50°
40°
30°
20°
10°
0°
10
20
30
40
50
60
70

The Moon aged 27 days, a day before New Moon. (*Lick Observatory*)

MOON. The Moon is our nearest neighbour in space, and for this reason it appears far more splendid than any other celestial body apart from the Sun. It is also the favourite object of study for the amateur astronomer, since even a moderate telescope will suffice to show it in considerable detail. Moreover, it is the first target for space travellers, since a voyage to the Moon is simpler than a longer journey to Mars or Venus. Yet the Moon itself is not a friendly world, since it lacks water, is subject to extremes of temperature, and has no atmosphere to provide oxygen or protection from radiation.

ORBIT. The Moon revolves round the Earth at a mean distance of 238,840 miles, which is less than ten times the distance round the Earth's equator. The orbit has an eccentricity of 0.055, the perigee and apogee distances being 221,593 and 252,948 miles respectively. The synodic period, or interval between successive New Moons, is 29 days 12 hours 44 minutes; the sidereal period 27 days 7 hours 43 minutes 11.5 seconds. The orbit is inclined at an angle of 5°, so that eclipses do not occur at every revolution (see **Eclipses**); the mean orbital velocity is 0.6 miles per second.

PHASES. Since the Moon has no inherent light, it exhibits regular phases from new to full. During the crescent stage, the darkened half of the Moon is often faintly visible. The first correct explanation of this phenomenon was given by Leonardo da Vinci, who realized that it is due to light reflected from the Earth (see **Earthshine**).

The boundary between the daylit and night hemispheres, known as the *terminator*, naturally appears rough and broken, since an elevation is bound to catch the sunlight in preference to an adjacent valley.

DIMENSIONS AND MASS. The Moon has a diameter of 2,160 miles, roughly one-quarter of that of the Earth. Compared with its primary, the Moon is far larger than any other known satellite, and in some ways it is better to regard the Earth–Moon system as a double planet (see **Satellites**). The density of the globe is 0.606 of that of the Earth, the mass being 0.0123 and the surface gravity 0.16.

ROTATION. **Tidal friction** in past ages has resulted in the rotation of the Moon being 'captured', or made equal to the period of rotation round the Earth. Consequently, the same hemisphere is always presented, and part of the surface we can never see from the Earth. We can however examine more than half the total area, since the varying velocity of the Moon in its orbit results in a slight tilting from side to side, known as libration in longitude, while there is also a libration in latitude due to the Moon's orbital inclination (see **Librations of Moon**). Only 0.411 of the total surface is permanently averted.

TELESCOPE APPEARANCE. Even in a small telescope, the Moon is a superb sight. In addition to the lofty mountains and the broad dark plains or 'maria', there are numerous walled circular formations (craters),

peaks, valleys, clefts, domes and many finer features. A 9-inch refracting telescope will show a crater only 1 mile in diameter.

Little direct lunar observation is done at the main observatories, though superb photographs have been taken at Mount Wilson and at the Pic du Midi. The best maps have been drawn by amateurs, in particular by Elger (1895), Goodacre (1930) and Wilkins (1946, revised in 1955), the latter being the most detailed chart now available. An official map was published in 1935 by the International Astronomical Union, but portions of it are not easy to interpret owing to their lack of clarity. A photographic atlas has been compiled in the United States.

MARIA. The seas, or *maria*, can be detected with the naked eye. The name is hardly appropriate, owing to the lack of water on the Moon, but it is probable that in past ages the maria were seas of lava; they must at any rate have solidified later than the bright uplands. The largest example is the *Oceanus Procellarum* ('Ocean of Storms'), which has an area almost twice that of the Mediterranean; the most perfect of the great seas is the *Mare Imbrium* ('Sea of Showers'), which covers 340,000 square miles, more than Great Britain and France put together.

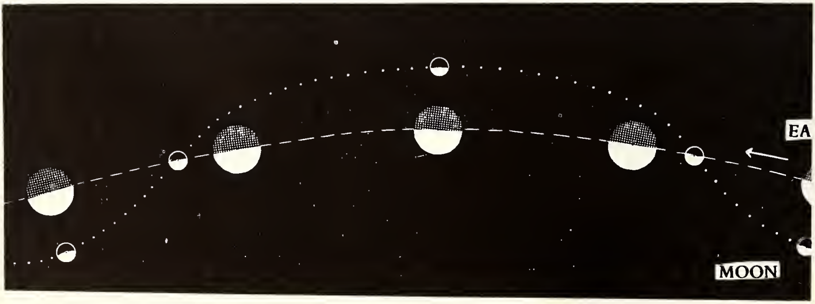
Of the smaller maria, *Mare Crisium* ('Sea of Crises'), with an area of 78,000 square miles, is particularly notable in view of its comparative isolation near the north-western limb. It is noticeable that the best-defined seas are basically circular, so that there would seem to be no essential difference between a *mare* and a crater except in magnitude.

MOUNTAINS. True mountain ranges are rather rare on the Moon, since most of the chains are in fact the 'walls' of *maria*. For instance, the Apennines and the Alps are portions of the border of the Mare Imbrium. The loftiest chains are the Leibnitz and Dörfel Mountains, in the far south, but these too may be the walls of *maria* lying on the averted hemisphere; recent measures indicate that they exceed 30,000 feet, and are thus loftier than Everest, though exact comparisons are difficult to make since there is no 'standard' on the Moon such as sea-level on Earth.

Separate peaks are common, and often attain great heights. Piton and Pico, on the Mare Imbrium, are prominent examples. Hills and hummocks are numbered in thousands.

CRATERS. The Moon is dominated by the walled circular formations known generally as craters. They are everywhere; they cluster thickly on the bright uplands, ruining and distorting one another, and they are found also on the maria, on the floors and walls of larger craters, and even on ridges and on the crests of peaks. No part of the Moon is free

THE MOON'S ORBIT. While circling the Earth, the Moon also follows the Earth in its path round the Sun, weaving in and out of the Earth's orbit. The diagram greatly exaggerates the effect, and the Moon's orbit is in fact convex everywhere.



THE MOON NEAR 'LAST QUARTER' photographed with the 100-inch telescope. The large isolated crater near the middle is Copernicus; below it and to the left are the Apennine Mountains. The two photographs were made at different dates, and show clearly the effects of libration. (*Mount Wilson – Palomar*)

from them, and each crater has its own points of individual interest.

When seen near the terminator, a crater gives the impression of great depth and precipitous walls. This is somewhat misleading. It is true that the depths are considerable (29,000 feet in the case of Newton), but in relation to its diameter a crater is comparatively shallow. Clavius, for instance, is 17,000 feet deep and 145 miles in diameter, so that in form it is more like a saucer than a well. A typical crater has a wall rising to only a moderate height above the surrounding country, but to several thousands of feet above the depressed interior.

It will be clear that an observer standing inside a crater would have no impression of being shut in by towering walls, particularly when the sharp curvature of the lunar surface is taken into account.

Many of the craters possess central mountains rising to considerable heights, though never to altitudes equal to the surrounding ramparts. Others have clusters of central peaks, while central craters are also fairly common. Some formations appear to be lacking in detail, and in small instruments appear smooth and mirror-like; but higher magnification will always reveal much fine detail, provided the seeing conditions are good. The Moon is a rugged world.

In size, the craters range from vast formations such as Bailly (diameter over 170 miles) down to tiny pits at the very limit of visibility. Their distribution is not random; from the largest plains to the smallest craterlets they tend to arrange themselves in chains, pairs and groups, while when one crater breaks into another the larger formation is almost always the sufferer. One object 55 miles across, Wargentin, has a raised floor, and is evidently filled to the brim with lava.

ORIGIN OF THE CRATERS. The problem of the origin of the walled formations has

MOUNT MERU CRATER, TANGANYIKA. An unusually well-rounded volcanic crater, but still very different from lunar craters. — An aerial view of a meteor crater is given in the article on Meteorites.

caused much heated argument, Some authorities attribute them to meteoric impacts, while others prefer the theory of igneous activity. Though there must be many meteor craterlets on the Moon, and it is not suggested that the lunar formations are in any way like terrestrial craters of volcanic origin, it is maintained by some authorities that the non-random distribution of the walled features is fatal to the hypothesis that all craters are due to impact. (See also relevant section under **Meteor**.)

Craters in the region of Clavius.
(*Mount Wilson – Palomar*)

BRIGHT RAYS. Some of the craters, notably Tycho and Copernicus, are the centres of systems of bright rays that extend for great distances across the Moon. Since they cross all other formations, and cast no shadows, they must be mere surface deposits; they may well be due to ash. In some cases, rays can be seen coming over the limb from the further hemisphere, and it has thus been possible to estimate the positions of several ray-craters which can never be actually seen from Earth.

MINOR FEATURES. Also to be found on the Moon are deep, narrow cracks or clefts; domes; shallow rimless pits, and other delicate objects. All these are of great interest and significance, but a full discussion of them is beyond the scope of the present section.

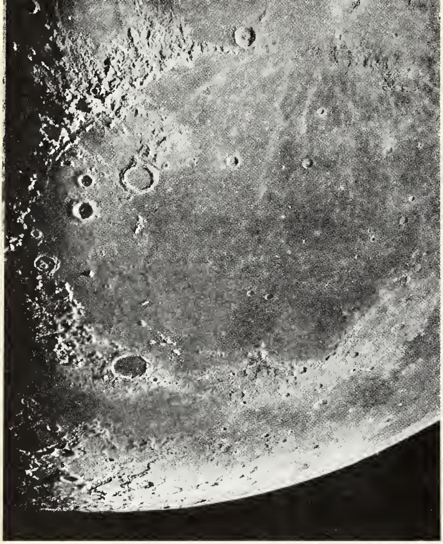
ATMOSPHERE. Since the Moon's escape velocity is only 1.4 miles per second, we can expect the atmosphere to be tenuous. Until very recently, it was thought that the ground density must be in the region of 1/10,000 of that of the Earth, but recent work has shown that this is a gross over-estimate. At present the question remains open. The density is certainly much less than 1/10,000, but it is unwise to state, as some authorities have done, that the Moon is totally devoid of an atmospheric mantle. The Moon *may* possess a very thin atmosphere made up of argon and other chemically inert gases, released by the decay of radioactive potassium.

Astronautically, the existence or non-existence of a tenuous mantle is most important With a ground density of 1/10,000, the lunar surface would be protected from the worst results of meteoric bombardment; if the density proves to be negligible, any artificial base constructed above ground will be in constant danger of being holed. So far, the results of various methods of research are discordant, and it is premature to come to any definite conclusions.

TEMPERATURES. Owing to the almost complete lack of atmosphere, the Moon's surface must experience great variations of temperature. The maximum at the equator is about 136° C. Higher latitudes are not so fiercely heated, and at lunar midnight the temperature anywhere on the surface sinks to that of freezing air. Experiments with

THE FAR SIDE OF THE MOON. The first view of a large part of the Moon that had never been seen before was obtained by Lunik III in 1959. From the position in which the photograph was taken the Moon appeared full, and many surface details that might have been revealed by their shadows remained invisible at this phase. Features marked with Roman numerals to the left of the broken line are visible from the Earth and are marked on the map on pp. 176–177; when making comparisons, it should be remembered that South is at the top of the map, and at the bottom of this photograph. (I) Humboldt Sea; (II) Sea of Crises; (III) Marginal Sea; (IV) Sea of Waves; (V) Smyth Sea; (VI) Sea of Fertility; (VII) Southern Sea. New features named by the Russians are marked with Arabic Numerals: (1) Moscow Sea; (2) Astronauts' Bay; (3) continuation of Southern Sea; (4) crater of main Tsiolkovsky Hill; (5) crater of Lomonosov Hill; (6) Joliot-Curie crater; (7) Sovietsky Mountain Range; (8) Dream Sea

The equator is indicated by the long solid white line; features enclosed by broken lines have not been named pending identification of their nature. The picture was transmitted dot by dot with signals that assigned any one of five degrees of 'greyness' to each dot; it compares well with photographs transmitted by a similar method by radio between news agencies, but high definition is not possible unless the picture is broken up into a very large number of dots, and this in turn requires a longer transmission time.



MARE IMBRIUM, whose few features include some interesting isolated peaks; at top left are the Appenine Mountains.
(*Mount Wilson Observatory*)

radio waves have however shown that the temperature below the surface layer is remarkably constant; the outer coating provides effective insulation.

It will be prudent to land some way from the equator, in order to avoid the very high temperatures. Von Braun has suggested the Sinus Roris, a comparatively smooth plain in about latitude 40° N., but no final choice can be made until more is known about local conditions.

NATURE OF THE SURFACE. Gold and others have suggested that the Moon is covered with a layer of loose material several kilometres deep, and that space-travellers will simply sink into the dust! Fortunately there are grave objections to this theory, and it is far more probable that the dusty layer is less than an inch deep, as is indicated by radio measurements. Parts of the crust may be unsafe, but at the moment we have no positive information.

Undoubtedly there is a good deal of dust on the Moon, both volcanic and meteoric, and this accounts for the almost complete absence of local colour. Elusive blues, reds and greens have been reported from time to time, but have never been confirmed, and must be regarded as highly dubious.

LIFE ON THE MOON. It is depressingly obvious that the Moon is not likely to harbour natural life. Animals are out of the question, owing to the generally unfavourable conditions and the lack of atmosphere and water. It is not impossible that very primitive plant forms may survive in a few places, but even this is unlikely, and it is reasonable to conclude that the Moon is a lifeless world.

CONDITIONS ON THE MOON. When the first space-travellers succeed in landing on the Moon, their troubles will be far from over. It will be necessary to build some form of base, and until we know more about the nature of the lunar crust it is difficult to decide upon procedure. Nor can we yet tell whether the lack of atmosphere will force us to 'go underground'.

If a semi-permanent colony could be established, the opportunities for research would be almost unlimited; but this lies in the future, and until we have learned more it is pointless to speculate.

RECENT RESEARCH. The most outstanding recent advances in our knowledge of the Moon stem from the signals sent by Lunik II up to the moment when it struck the Moon's surface, which indicated that the Moon's magnetic field is some four thousand times weaker than that of the Earth, and from the photographs obtained by Lunik III.

There is some inconclusive evidence that there is an active volcano in the Alphonsus crater. A Russian astronomer observed a reddish cloud in the area in 1958, and spectrograms gave some indication of the presence of gases. This reddish patch was also noted by other observers, but some failed to detect any trace of it. (P.M.)

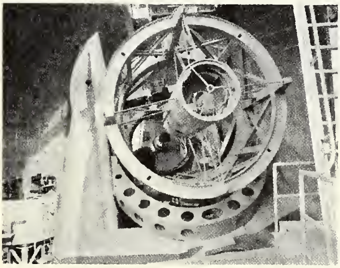
MOON CAMERA, DUAL-RATE. An instrument recently invented by Dr. William Markowitz to improve the accuracy of geodetic measurements. (See **Geodesy**.) The

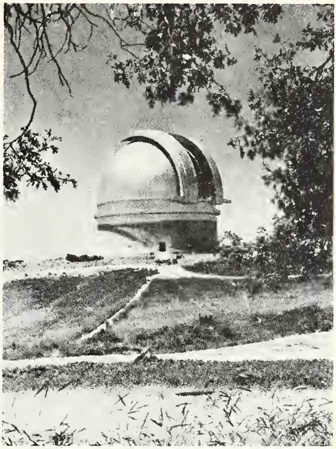
measurements are made by photographing the Moon and its background of stars. Owing to the comparative proximity of the Moon, the parallactic shift observed between widely separated stations is large; but hitherto the accuracy of observations has been severely limited by the rapid motion of the Moon relative to the stars during the exposure. In the Markowitz camera, this movement is counteracted: the image of the Moon falls upon a glass plate just large enough to receive it, and the plate is slowly rotated about a diameter at the correct rate. Refraction occurs at the surfaces of the glass plate and the lunar image is continuously displaced at just such a rate as to keep its position fixed on the photographic plate relative to the stars; the camera as a whole is of course driven round at the sidereal rate to follow the stars. A number of these instruments were employed on fundamental geodetic work during the **International Geophysical Year**.

MOON PROBE. A rocket with instruments designed to collect and transmit information on the Moon and the space surrounding it. See **Artificial Satellite.**

MOONS. Satellites of planets, a moon being in the same relation to its planet as the planet is to its primary. Of the nine planets in the Solar System, six have a total of thirty-one moons; their origin is not known, nor has it been possible to determine whether stars other than the Sun possess planets and moons.

THE OBSERVER'S CAGE at the prime focus of the 200-inch telescope; an astronomer is riding in the cage.

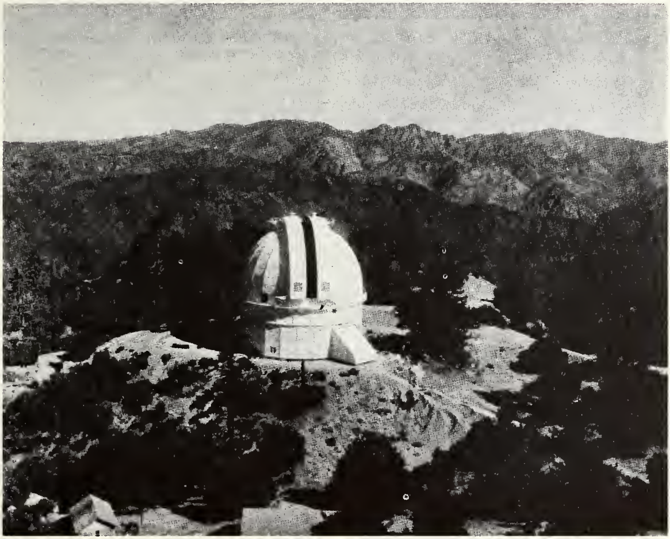




MOUNT PALOMAR OBSERVATORY in southern California, U.S.A., has the largest optical telescope in existence, with a mirror 200 inches in diameter. The instrument is almost invariably used photographically. The mirror is so large that no great obstruction is caused by the observer (who must be constantly vigilant during an exposure to keep the telescope correctly aligned) sitting in a 'cage' in the upper end of the telescope tube. The observer is carried round with the telescope, which turns on an ingenious type of mounting: the northern bearing is shaped like a horseshoe 46 feet across, and the telescope can look between its arms to observe objects near the north celestial pole. The telescope and moving parts of the mounting together weigh 500 tons.

Palomar also has the largest Schmidt telescope in the world, with an aperture of 48 inches. It takes photographic plates 14 inches square, and was occupied for over seven years by the 'Sky Survey' whose result is a monumental atlas containing nearly 2,000 photographs covering all the sky accessible from Palomar.

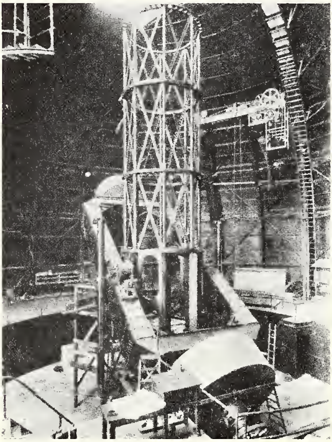
MOUNT PALOMAR OBSERVATORY – the 200-inch dome photographed by moonlight. A sectional drawing of the 200-inch telescope itself will be found in the article on Telescopes.



MOUNT WILSON OBSERVATORY: the dome housing the 100-inch telescope – a view taken from the 150 ft. tower.

Above: the 150-foot tower telescope at Mount Wilson Observatory.

Below: the 100-inch reflector at Mount Wilson.



MOUNT WILSON OBSERVATORY is situated on a mountain top 5,960 feet above sea level, in California, U.S.A. It possessed for several decades the largest telescope in the world, a 100-inch reflector.

This instrument and a 60-inch have done sterling work since the beginning of the century, especially in the photography of faint nebulae beyond the reach of lesser telescopes. Mount Wilson also has two 'tower' telescopes used for observing the Sun. In such instruments the image is reflected into a subterranean observing room by a moving mirror on top of a high steel tower, and the worst effects of atmospheric turbulence caused by ground heating are avoided.

MULTIPLE STAR. See **Binary Star.**

N

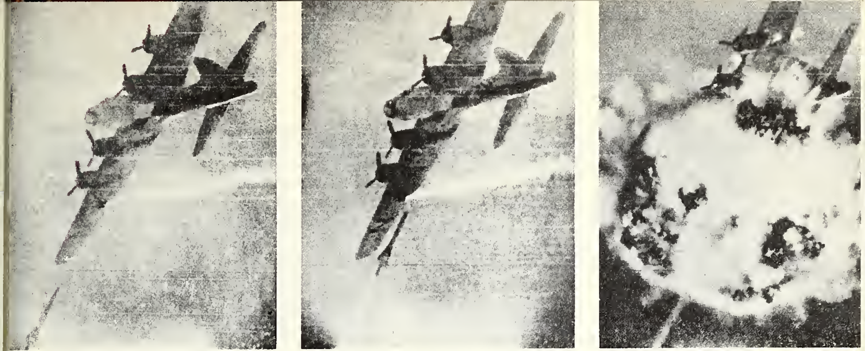
NADIR. The point on the celestial sphere opposite the zenith and therefore vertically beneath the observer.

NAUTICAL ALMANAC. A book which gives the **ephemeris** or time-tables of predicted movements of celestial bodies for a whole year, in so far as they can be of value in navigation.

NAVAHO. A surface-to-surface winged intercontinental **missile** of the U.S. Air Force.

NEBULAE. See **Galactic Nebulae,** and **Extragalactic Nebulae.**

NEPTUNE. The outermost of the four giant planets. It was first recognized in 1846, by Galle and d'Arrest at the Berlin Observatory, but the discovery was not due to pure chance. Uranus had been wandering from its predicted orbit, and Le Verrier, a French mathematician, had decided that an unknown planet must be responsible. By careful calculation he had worked out just where the new body must lie, and all that Galle and d'Arrest had to do was to search in the position indicated. Actually, a Cambridge graduate, John Couch Adams,



had reached the same solution some time before, but the search in England was not carried out with the same energy as on the Continent. It is now agreed that the honour for the tracking-down of Neptune must be shared equally between Le Verrier and Adams.

ORBIT. Neptune's perihelic, mean and aphelic distances from the Sun are 2,769, 2,793 and 2,817 million miles respectively. The orbital eccentricity is 0.009, lower than that of any other planet except Venus; the inclination is 1°.8, and the mean orbital velocity 3.4 miles per second. Neptune has a sidereal period of 164.8 years, so that it has completed less than three-quarters of a revolution since its discovery.

DIMENSIONS AND MASS. Neptune has a diameter of 27,600 miles, and is thus rather smaller than Uranus. It has however a greater mass, 17 times that of the Earth; and the density is 2.2 times that of water, appreciably greater than for the other giants. The surface gravity (1.4 times that of the Earth) is higher than for any other planet except Jupiter, and the escape velocity is 16 miles per second.

ROTATION. The curious axial tilt of Uranus is not shared by Neptune (see **Uranus**). The inclination of the equator to the orbit is only 29°. The axial rotation period is not easy to determine, but appears to be about 15 hours 48 minutes.

SURFACE FEATURES. Owing to its remoteness, Neptune shows little or no surface detail. The colour is bluish, and differs from the green hue of Uranus.

NIKE destroying a four-engined target bomber during trials. The missile is approaching from lower left.

TEMPERATURE AND COMPOSITION OF THE GLOBE. The temperature of Neptune seems to be about −200° C. There is no reason to suppose that the globe is built in a manner radically different from that of the other giants (see **Jupiter**). On Wildt's model, the rocky core is 12,000 miles in diameter, while Ramsey considers that the composition of Neptune is almost identical with that of Uranus.

SATELLITES. Less than three weeks after Neptune itself had been discovered, it was found to possess a large satellite that has been named *Triton*. It appears to be almost the equal of *Titan* (see **Saturn**), with a diameter of over 3,000 miles; it lies 220,000 miles from Neptune, and has a sidereal period of 5 days 21 hours. The orbit has low eccentricity, but high inclination, and the motion is retrograde. Despite its size, Triton would not be a brilliant object in Neptunian skies, as it would shed only 1/400 the light of our Full Moon.

Triton must have an escape velocity of at least 2 miles per second, and should therefore be capable of retaining an atmosphere. Indications of a methane mantle have been suspected, but definite proof is still lacking.

Nereid, the second satellite, was discovered in 1949. It is only about 200 miles in diameter, and has a remarkable orbit, the eccentricity being 0.760. The sidereal period is 359 days, and the motion direct.

SUMMARY. Neptune and Uranus may be considered as true twins, and are far more

similar than Venus and the Earth. The main difference is that Neptune is slightly smaller, slightly denser, slightly more massive and appreciably colder.

So far as is known at present, Neptune is the last member of the group of giant planets. If another exists, it must be so faint that its discovery will be a matter of extreme difficulty. (P.M.)

NEUTRAL POINT. The point on the line joining Earth and Moon at which the gravitational fields of the two bodies just cancel each other. Neutral points, of course, exist between other pairs of neighbouring bodies.

NEUTRON. A particle that exists in the nuclei of all **atoms** except those of normal hydrogen. The neutron's mass is nearly equal to the mass of a hydrogen atom, but unlike the proton and the electron it possesses no electrical charge, and this accounts for its relatively late discovery (1930).

N.G.C. Abbreviation for the *New General Catalogue* of nebulae and star clusters.

NIKE. A surface-to-air, short-range interceptor rocket **missile** of the U.S. Army with command guidance.

NOCTILUCENT CLOUDS. Peculiar clouds at heights of about 50 miles in the Earth's atmosphere. They can be seen at night as, owing to their altitude and to the bending of sunlight by atmospheric refraction, they are still illuminated by the Sun long after nightfall on the Earth's surface.

NODE. One of the two points in which the line of intersection of any two planes cuts the **celestial sphere**. In the solar system, it is one of the points in which the Moon's or a planet's orbit cuts the ecliptic.

When the Moon or a planet crosses the plane of the Earth's orbit from South to North it passes through the *ascending node*; when it crosses from North to South it passes through the *descending node*.

A body may not cross the ecliptic in the same point every time. This causes its nodes to move slowly forwards or backwards along the ecliptic, a phenomenon which is called *progression* or *regression of the nodes*. The nodes of the Moon regress so that each makes a complete circuit of the ecliptic in about 19 years.

NOMENCLATURE OF STARS. Most of the brightest stars have names of their own as well as systematic designations. For easy reference, the sky is divided into 88 **constellations**, of differing sizes, bounded by lines of Right Ascension and Declination for the epoch 1875. In each constellation the brightest stars are given Greek letter prefixes, in approximate order of brightness, followed by the name of the constellation. When the Greek alphabet is exhausted, small English letters are used, and finally English capitals.

All stars down to about the sixth magnitude also have numbers within each constellation, and these, called Flamsteed Numbers after the astronomer who allotted them, are now generally used in preference to English letters.

Stars down to almost the tenth magnitude have been catalogued in the monumental **Bonn Durchmusterung**. This takes no account of constellations, stars being named by their declination and a number. Thus B.D. $+59°$ 1376 is star number 1376 in the zone between declinations $+59°$ and $+60°$. The brightest star in the northern hemisphere is Vega or α-Lyrae; in the Flamsteed catalogue it is 3 Lyrae, and in the Durchmusterung it is B.D. $+38°$ 3238.

Variable stars have their own designations, described under their own heading.

NOVA (literally 'new one'): a star which undergoes a sudden and enormous increase in brightness. See also **Supernova**.

About 25 novae appear every year in our Galaxy. Of these, most are only discovered long after their outbursts during investigation of photographic plates; but a few, which are relatively close to us, reach naked eye brightness and are discovered almost immediately. These latter are the ones which we are able to study at the most interesting time, near the maximum.

Faint stars have been found recorded on plates taken before a nova outburst in the position of the nova. The only two known pre-nova spectra are those of a normal A star and G-type giant. The outburst is characterized by an extremely rapid rise of brightness through about 12 magnitudes (representing a

60-thousand-fold gain in brilliance) in something like two days. Two novae this century, those in Perseus in 1901 and Aquila in 1918, have reached zero apparent magnitude. The absolute magnitude of a nova at maximum is around -8. Typical behaviour after maximum is an immediate decline, rapid at first but soon becoming slower and having superimposed on it rapid and erratic fluctuations. These short-term oscillations die away after a few months and the star gradually sinks to an unsteady magnitude around its pre-nova level.

During the outburst the star's surface is expanding – we see it hurtling towards us at one or two thousand kilometres per second – and at maximum light the surface bursts and material is thrown off in many directions.

While all novae have their own peculiarities, the behaviour of T Aurigae 1891 is significant because it was repeated by DQ Herculis in 1934. The latter reached nearly first magnitude, declined irregularly and rather slowly to fifth and then suddenly and without warning fell to the thirteenth magnitude. It immediately recovered almost to sixth magnitude and continued its decline. Some other novae develop remarkably slowly: the extreme example is RT Serpentis which exploded in 1909.

Some novae have exploded more than once; for instance T Pyxidis has exploded four times in seventy years. These novae have a smaller range of luminosity than normal novae. The resemblance between the initial and final states of a nova, and the possibility of recurrent outbursts, strongly suggests that the explosion is quite superficial and has little effect on the star as a whole: it is probably some form of safety-valve mechanism for the star. It may well be that all novae are recurrent, the period of ordinary novae being comparable with a million years.

A few variable stars with very peculiar spectra seem to be related to novae. One of these, η Carinae, after a highly irregular rise of brilliance through several decades, reached -1 magnitude in 1843, when it ranked second only to Sirius in brightness; thereafter it slowly declined, reaching seventh magnitude in 1880. It is now between eighth and ninth magnitude.

We do not know what causes a nova to flare up. There are many arguments against collisions being the cause; possibly the outburst happens when some critical stage is reached in processes deep within the star. (R.G.)

NUCLEAR PROPULSION. Atomic energy offers a form of rocket propulsion far superior to chemical motors. Many difficulties crop up in the practical realization of this promise. The fissionable material is used up extremely slowly and cannot itself form the exhaust, which must therefore be composed of some *working fluid*. The working fluid is heated and vaporized by the reactor, and the hot gas is expelled with great velocity.

Any form of atomic motor carries a large weight penalty owing to the necessity for heavy screening to protect the rest of the rocket from harmful radiations, and this leads to a low **mass ratio**. (See also **Nuclear Reaction**.)

NUCLEAR REACTIONS. When an **atom** is bombarded with particles such as neutrons, the effect in most cases is not very catastrophic: the nucleus of the bombarded atom may for instance absorb a neutron and perhaps emit some other particle. In the case of the isotope of uranium of atomic weight 235, however, such bombardment with neutrons can split the atomic nucleus into two more or less equal parts, with the liberation of several more neutrons and a great deal of energy. This process is *nuclear fission*. In a large lump of uranium the newly emitted neutrons cause the fission of other atoms before they can escape from the lump, and a chain reaction is initiated which builds up from small beginnings like an avalanche within less than one second. This is the principle of the atomic bomb; it has been modified in nuclear reactors, where instead of one large lump being used several smaller pieces of fissionable material are placed at such distances from each other that the chain reaction maintains its own level and does not grow out of control.

A few elements besides uranium have fissionable isotopes.

At the other end of the atomic weight scale, several lighter nuclei can give up energy by *nuclear fusion*: joining together to give a heavier nucleus. This process can only take place if a tremendous amount of energy is first invested to trigger it off. Hence, hydrogen bombs are detonated by exploding a fission bomb. A great deal of research is being carried

out to harness the power of fusion processes by stabilizing the reaction, *e.g.* by restricting it inside a powerful ring-shaped magnetic field as in the British Zeta apparatus. Temperatures must be produced comparable to those in the interior of the Sun and other stars, where fusion processes occur naturally. (See **Stellar Energy**.)

NUTATION. A small oscillation or 'wobble' in the Earth's axis in addition to precession, with a cycle of 19 years. It is caused by the Moon's tendency to pull the Earth's equatorial bulge into line with its gravitational attraction. See **Precession**.

O

OCCULTATION. The disappearance of a star behind the disc of the Moon or of a planet, or of a satellite behind its primary. An occultation is basically an **eclipse**. Occultations by the Moon are of great value in the accurate determination of its orbit. They also confirm that the Moon can have none except the most tenuous atmosphere, since the occultation of a star is always very sudden and without traces of atmospheric refraction at the Moon's surface.

OCTANT. A form of **sextant**, with a graduated rim forming roughly one-eighth of a circle.

OCTOBER DRACONIDS. A **meteor** shower which gave spectacular displays in 1926, 1933 and 1946 when the Earth passed through the orbit of the Giacobini-Zinner comet shortly before or after the comet itself.

OPPOSITION. See **Conjunction**.

ORBIT. The path in which a celestial body moves about the **centre of gravity** of the system to which it belongs. Every orbit is basically in the shape of a **conic section** with the centre of gravity at one focus.

The Sun is so massive in comparison with the planets that the centre of gravity of the solar system is always in or very near to it. All other members of the system therefore move in more or less elliptical orbits around the Sun.

An orbit is completely described if six of its characteristics or *elements* are stated. The six elements usually given for planets are:

1. ECCENTRICITY, which determines the shape of the orbit, whether it is hyperbolic or elliptical, elongated or nearly circular.

2. SEMI-MAJOR AXIS, which fixes the size.

The next three elements describe the orbit's orientation in space:

3. INCLINATION is the angle between the plane of the orbit of the planet and the plane of the Earth's orbit, i.e. the ecliptic.

4. LONGITUDE OF ASCENDING NODE tells us the direction of the point in which the planet crosses the ecliptic from South to North.

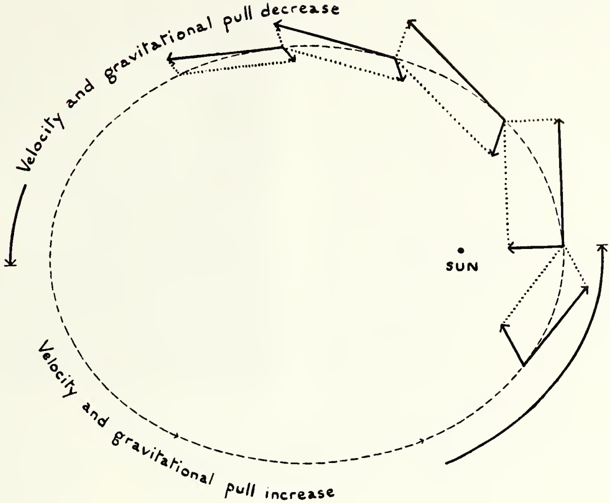
5. LONGITUDE OF PERIHELION states how far around the orbit the point on it nearest to the Sun lies as measured from the ascending node.

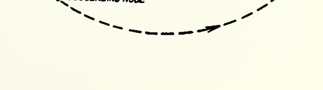
Now the shape, size and orientation of the orbit are fixed. To find how a planet moves in this orbit we only need to know –

6. TIME OF PERIHELION PASSAGE on any one occasion. This provides a starting point for reckoning based on **Kepler's third law**, from which we can calculate the position and orbital speed of the planet at any other time, *provided* we already know the mass of the Sun (or, more strictly, the mass of the entire solar system). Failing this, a seventh element is required; viz.

7. PERIOD or time taken to complete one circuit of the orbit.

The orbit of each member of the solar system is perturbed by the other members; Jupiter's influence is particularly powerful, and has profoundly affected many asteroid, comet and meteor orbits. Some of the last two have hyperbolic orbits: they approach the Sun once and recede again, never to return. All others move in elliptical paths. A





A PLANETARY ORBIT. At every point in its orbit, two forces act on a planet: the Sun's gravitational attraction, and the planet's own momentum. In the upper diagram, the length of the arrows pointing inwards at the Sun is drawn proportional to the gravitational force, while the other arrows represent momentum which in turn depends upon the velocity of the planet at that part of its orbit. If a parallelogram is completed as shown, the direction of advance of the planet lies along the diagonal of the parallelogram. The forces act continuously, so that the path is curved everywhere. The diagram at lower left shows why the *apparent* motion of outer planets such as Mars displays S-shaped loops.

parabolic orbit cannot in practice be followed, because the slightest perturbation converts it into either a hyperbolic or an elliptical one.

Outside the solar system the ecliptic becomes irrelevant as a plane of reference, and inclination is usually measured relative to the plane at right angles to the line of sight.

There is a close connection between the shape and size of an orbit and *orbital velocity*. The Earth, for instance, travels around the Sun with an average speed of $18\frac{1}{2}$ miles per second, in a slightly elliptical path. If somehow it were to slow down a little when it is at perihelion, its orbit would become more nearly circular, and if it continued to slow down it would gradually spiral towards and into the Sun. If, on the other hand, it increased its speed, its orbit would elongate, and for a particular speed called *parabolic velocity* the orbit would 'split' at the far end of the ellipse, so that instead of returning the Earth would escape entirely from the solar system. The same principle applies to all orbits, including those of artificial satellites and space ships, and explains why parabolic velocity is often called **escape velocity**. The least speed for maintaining an orbit *at a given distance* from the centre of attraction and the least speed for escaping from it altogether are connected by the equation:

$$\textit{Parabolic vel.} = \sqrt{2} \times \textit{circular velocity.}$$

(M.T.B.)

ORBITAL PERIOD. See Sidereal Period.

ORBITAL REFUELLING. Strictly speaking this should be called orbital *repropellenting*, since in addition to the fuel itself an ordinary chemical rocket must also carry the oxidant in which the fuel is burnt.

Even a gigantic rocket can take only a very limited **payload** into a closed orbit round the Earth, and if such a rocket is manned, most of this payload will consist of the crew, their cabin, supplies and instruments. It is not possible to carry enough propellent in addition to escape from the closed orbit, unless the rocket can take on board propellent in the orbit. This is quite feasible; unmanned tanker rockets could be sent into the orbit, their payloads being entirely in the form of spare propellent and its container. The tanks could remain in the closed orbit indefinitely until a manned spaceship moves up to them in the orbit and transfers their contents to itself; the manoeuvre would demand very little extra energy.

REFUELLING FROM A TANKER ROCKET IN ORBIT. This operation, like the assembling of space stations in orbit, is almost certain to be redundant before it is practicable.

It is, however, unlikely that such a method will ever be employed. It is far more probable that, before the need for orbital refuelling could ever arise, chemical rockets will have been superseded by rockets with **nuclear propulsion.**

ORION. Perhaps the most striking of all constellations. It is prominent in the winter sky in northern latitudes. Orion was a hunter in ancient mythology. The three stars in a line are said to represent his belt, and the line below it, including the **Orion Nebula**, contains the stars that are the jewels on his sword.

ORION NEBULA. The brightest of the gaseous nebulae in our galaxy (see **Galactic Nebulae**). The naked eye sees it as a haze around the interesting multiple star υ Orionis.

THE HORSEHEAD NEBULA, a region of dark absorption and glowing emission nebulosities near the star Zeta Orionis. A number of foreground stars are seen which lie between the Earth and the almost opaque dark areas. The picture is shown here with South towards the top edge, as is customary with astronomical photographs.

ORIONIDS. A meteor shower with multiple radiants; it is most active about October 20, and may be associated with **Halley's Comet**.

OXYGEN. A chemical element, whose atomic nuclei contain eight protons. Oxygen forms about one-fifth of the Earth's atmosphere, and is essential to almost all forms of terrestrial life. It can be liquefied at normal pressure at a temperature of −183° C.; liquid oxygen is often used as an oxidant in rocket motors.

There is little oxygen in the atmospheres of the other planets, and its abundance on the Earth may be due to its release by green plants.

P

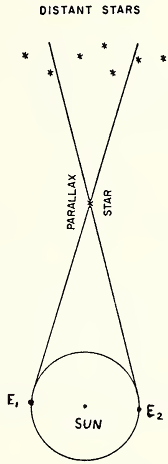
PALLAS. The second largest of the minor planets, discovered by Olbers in 1802. It has a diameter of 304 miles, inferior only to **Ceres**. The orbital period is 4.61 years; the orbit has the exceptionally high inclination of 34° 44′. At its brightest, Pallas shines as a star of magnitude 8. (See **Asteroids**.)

PARABOLA. See **Conic Sections**.

PARABOLIC VELOCITY. The velocity which a particle must possess in order to describe a parabolic **orbit** in the gravitational field of another body. This is a boundary case: a slighter lower velocity causes the particle to move in a closed ellipse, while a slightly greater speed gives it a hyperbolic orbit in which it never returns to the same vicinity. Parabolic velocity is the minimum escape velocity. (See **Orbit**.)

PARALLAX. The difference between the directions in which an object is seen from two places at the same time.

The separation of the viewpoints is called the *baseline*. For example, the separation of our eyes is constantly being used as a baseline, and from the parallax we judge how far away things are. Baselines of thousands of miles between observatories in different parts of the world serve for determinations of the parallax of the Moon, from which can be found the size of its orbit.



WHILE THE EARTH MOVES THROUGH HALF OF ITS ORBIT, nearby stars appear to shift against the background of the more distant stars. This parallactic shift allows the distances of the nearer stars to be calculated by triangulation.

The solar parallax is never measured directly for a variety of reasons; the parallax of a reasonably close member of the solar system is obtained instead (Venus, Eros and other asteroids have been used) and the solar parallax derived from this. The latter must be accurately known because on it depends the value of the **astronomical unit**, the mean distance of the Earth from the Sun, which is fundamental in many other measurements.

The stars are so far removed that it is necessary to use a larger baseline: the diameter

Left: THE GREAT NEBULA IN ORION, a vast mass of gas illuminated chiefly by high-temperature stars within the black circle. The naked eye sees it as the middle star in the Sword of Orion, but a long exposure reveals that the nebula covers an area of the sky larger than the Moon's disc. (*Yerkes*)

of the Earth's orbit. As the Earth makes its annual journey round the Sun, the nearest stars appear to describe tiny circles against the background of stars which are too far away to show any appreciable parallax. Refined methods permit quite exact distances to be found in this way. (See also **Parsec.**)

PARSEC. A unit of distance equal to 19,150,000,000,000 miles. The word *parsec* is a contraction of *parallax second*, i.e. the distance at which the mean radius of the Earth's orbit would subtend an angle of one second of arc. If a supersonic aircraft had taken off in the days of Julius Caesar it would by now have covered less than one thousandth of a parsec. Our Galaxy has a diameter of 30,000 parsecs approximately.

The parsec is compared with other units in the table under **Distances.**

PASCHEN SERIES. A sequence of lines in the infra-red region of the hydrogen spectrum. See **Spectroscopy.**

PAYLOAD. The weight of everything in a rocket or missile that can be described as 'useful cargo', such as scientific instruments, passengers, supplies or, in the case of weapons, the warhead. The payload is usually less than a tenth of the total weight of the missile with full propellent tanks.

In a step-rocket, the payload of each step except the last consists of the succeeding steps.

PENUMBRA. See **Umbra.**

PERIGEE. The point in the orbit of the Moon or of an artificial satellite which is nearest to the Earth. Opposite of *Apogee.*

PERIHELION. The point closest to the Sun in the orbit of any member of the solar system.

PERSEIDS. A **meteor** shower with a very regular maximum on August 12.

PERSONAL EQUATION. A small correction which is applied to observational measurements made by one individual. It compensates for systematic errors which arise from personal idiosyncrasies, for instance in judging the exact moment at which a star crosses a hairline in the field of view of a telescope. The correction may be determined by statistical methods, and has of course a different value for each type of observation.

PERTURBATION. The effect of the gravitational pull of one body upon the orbit of another. It leads to small regular or irregular departures from what would otherwise be a smooth orbit having the shape of a **conic section.** Thus the attraction of the Moon causes the Earth to 'weave' somewhat in its elliptical path about the Sun; Jupiter's satellites perturb each other as well as Jupiter itself; and comets may be so perturbed by planets near their course that the latter is entirely changed.

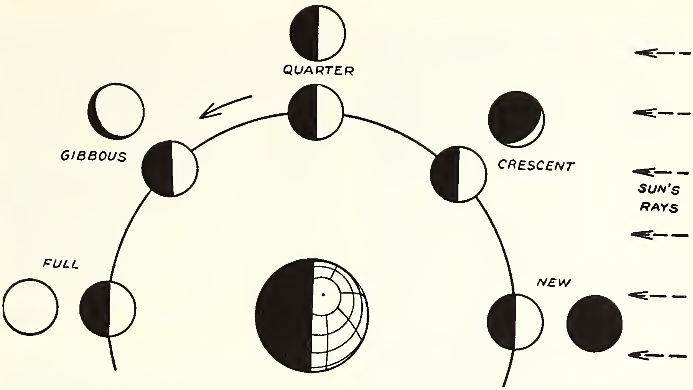
The most accurate determinations of the masses of planets are made by noting the perturbations caused by their satellites or by other planets. Irregularities in the orbit of Uranus led to the prediction of the existence of a planet which perturbed Uranus, and so to the discovery of **Neptune** near the predicted position.

PHASES. The varying apparent shapes of the Moon and the inner planets.

The planets in the solar system, their satellites and our Moon shine by reflected light from the Sun, and consequently only half the surface of each is illuminated at any one time. Unless we happen to see just this half, the object does not appear to be circular in outline but exhibits a *phase.* It may look crescent, semicircular or gibbous. The planets beyond Mars do not show phases because the Earth is so close to the Sun that we are always looking from virtually the direction from which the solar rays illuminate them. Mercury and Venus, like the Moon, can show any phase from New to Full.

The horns of the crescent phase always point away from the Sun. A little consideration will show that the Full Moon must rise roughly when the Sun sets, and that the crescent phase can never be above the horizon in the middle of the night.

PHOBOS. The inner satellite of Mars. It is a tiny body, only about 10 miles in diameter, and is so close to its primary that it revolves round Mars in less time than Mars takes to spin on its axis. It was discovered in 1877. (See **Mars.**)



PHASES OF THE MOON; their appearance as seen from the Earth is given by the outer ring of the diagram.

PHOTO-IONIZATION. The removal of electrons from an **atom** by light or other radiation. See **Ionization.**

PHOTOMETRY. The measurement of the intensity of light. It is of particular importance in the study of **variable stars.**

PHOTON. The 'packet' of light or other **electromagnetic radiation** which possesses one **quantum** of energy. It is owing to the emission of radiation in discrete photons that light sometimes behaves like a stream of corpuscles.

PHOTOSPHERE. The layer of the **Sun's** surface that we normally see.

PHYSICAL UNITS. Some of the physical units and constants that have been used repeatedly in this book are brought together here for convenience, as well as certain basic definitions. Common abbreviations are given in brackets.

THE METRIC SYSTEM.

1 kilometre (km.)	= 1,000 metres or 0.621 miles.
1 metre (m.)	= 100 centimetres or 39.37 inches.
1 centimetre (cm.)	= 10 millimetres.
1 millimetre (mm.)	= 1,000 microns.
1 micron (μ)	= 10,000 Angstrom (Å).

1 GRAM (gm. or g.) is the mass of one cubic centimetre of water at a temperature of 4 degrees Centigrade. (See **Gravitation** for the distinction between mass and weight.)

DENSITY of a substance is its mass per unit volume.

FORCE is that which tends to alter the uniform motion (or rest) of a body. Force is stated in terms of the weight that exerts an equal force, i.e. a force of *a* lbs. weight or of *b* gms. weight.

FORCE can also be measured by the acceleration it can produce: a force of 1 *dyne* will accelerate a mass of 1 gram by 1 cm. per sec. per sec.

WORK is done when a force moves its point of application. It is expressed as the product of the force and the distance through which it has moved its point of application without diminishing or getting stronger, i.e. as *a* ft.lbs. or *b* gram-centimetres, or in ergs.

1 *erg* = 1 *dyne-centimetre.*

ENERGY is the ability to do work. It is measured in the same units as work.

POWER is the rate of doing work. It is

measured in units of work per unit time, e.g. in gm.cm./sec. or ft.lbs./sec.

SPEED is the distance covered in any direction per unit time. It is expressed in cm./sec. or miles per hour (m.p.h.) or any equivalent combination, and can never be negative.

VELOCITY is speed *in a given direction.* It is measured in the same units as speed, but a motion in a direction opposite to the given direction has negative velocity.

ACCELERATION is rate of increase of velocity. It is stated as the change of velocity per unit time, e.g. as (centimetres per second) per second. The expression in brackets here represents the velocity change that accrues during one second. A more usual form of writing the units is as a ft./sec.^{2} or b cm. sec.$^{-2}$. A negative acceleration is a *retardation.*

HEAT is measured in *calories.* One calorie is the amount of heat required to raise the temperature of one gram of water by one degree Centigrade (from 14.5° to 15.5°). One degree Centigrade is one hundredth of the difference of temperature between melting ice and boiling water (at normal pressure).

Temperature = heat per unit mass.

PRESSURE is stated as force per unit area, e.g. lbs. per square inch. It is also given in *millibars* (1,000 dynes per square centimetre) or as the height of a column of mercury which exerts such a pressure. *Normal atmospheric pressure* equals 760 mm. of mercury or 14.79 lbs. per square inch or 1,013.4 millibars.

PIONEER. The name given to a family of **artificial satellites,** lunar probes and a **Venus Probe.** Several are in orbit now.

PIRANI GAUGE. An instrument for measuring low gaseous pressures. A stream of the gas is allowed to cool an electrically heated wire; pressure variations show up as changes in the current flowing through the heated filament.

PLANET. A satellite of a star. The only planets known are the nine belonging to our Sun. Their origin is uncertain, but it is reasonable to suppose that the Sun is not unique among stars in possessing them. As yet, no methods are available by which planets of other stars could be detected.

None of the planets of the solar system give out any light of their own; they are rendered visible by the reflection of sunlight. Strictly speaking, they revolve in orbits not around the Sun but around the common centre of gravity of the whole system. See **Solar System** and the entries for the individual planets.

PLANET, ARTIFICIAL. See **Artificial Satellite.**

PLANETARY PROBE. A rocket designed to approach or land on other planets and telemeter information to the Earth about conditions on the surface of and in space near to the planet.

The use of such probes is essential in paving the way for manned vehicles. Their trajectories require elaborate calculation and the highest accuracy in launching, and radio communication over the vast distances involved poses considerable problems. See **Venus Probe** and **Transfer Ellipse.**

PLANISPHERE. A small-scale star map showing the whole sky, and provided with an oval aperture through which only part of the map can be seen. It is so arranged that this part corresponds to the hemisphere of sky visible at a particular time, and the position of the aperture can be adjusted for any time and date to show what constellations are then above the horizon. (See also **Star Globe.**)

PLASMA. A fourth state of matter (neither solid, liquid, nor gaseous in the conventional sense) consisting of highly ionised atomic nuclei and free electrons. For its applications to astronautics, see **Rocketry**.

PLEIADES. The finest **galactic cluster** in the sky. The naked eye sees it as a group of stars in the constellation Taurus. The Pleiades are mentioned in the Bible and were named the *Seven Sisters* by the Ancients. Only six stars are now normally visible, and there are many old myths about the 'lost Pleiad'; presumably some change has taken place. On a really dark night the sharp eye may be able to detect as many as eleven or even fourteen.

THE PLEIADES CLUSTER, whose stars are embedded in wisps of nebulosity. (*Roberts*)

PLUTO is generally called 'the outermost planet', but this term is not always correct. It is true that Pluto's mean distance from the Sun is much greater than that of Neptune, but the eccentric orbit can bring it within the perihelion distance of Neptune. The next perihelion passage occurs in 1989, and from 1969 to 2009 Pluto will not mark the far boundary of the planetary system.

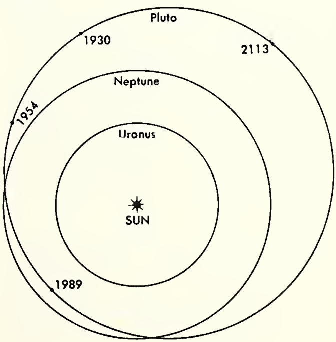
DISCOVERY. Even after Neptune had been found, there were still some unexplained perturbations in the movements of the outer giants. These perturbations were studied by Lowell and W. H. Pickering, and the position of a hypothetical planet was deduced. For a long time the new planet refused to reveal itself; it was eventually discovered in 1930, very close to the predicted position. The delay was due to the fact that Pluto is much smaller and fainter than Lowell had supposed.

ORBIT. Pluto's mean distance from the Sun is 3,666 million miles. The orbital eccentricity is very high, 0.248, and at perihelion the planet approaches the Sun to 2,766 million miles (three million miles closer than Neptune at its nearest), while the aphelion distance is 4,567 million niles. The inclination, 17°, is also much higher than that of any other planet. The sidereal period is 248 years, and the mean orbital velocity 3 miles per second.

DIMENSIONS AND MASS. Pluto is not a giant world, and in view of its remoteness its diameter is difficult to measure. According to Kuiper, Pluto is smaller than Mars, with a diameter of 3,600 miles. Assuming a normal density, this would make the mass less than 1/10 of that of the Earth.

This raises problems. A body of this insignificant nature could not perturb giants like Uranus or Neptune to any appreciable extent; yet it was from these very perturba-

The eccentric orbit of Pluto. Owing to the inclination of the orbit, Pluto and Neptune can never collide.



PLUTO'S MOTION IN 24 HOURS. (*Mount Wilson – Palomar*)

tions that Pluto was tracked down. Either we must suppose that its discovery was pure luck, or else we must suppose that Pluto is more massive than the diameter measures indicate.

It seems unlikely that both Lowell and Pickering could have independently reached the correct answer by sheer chance, and equally unlikely that Pluto has a high density. It has been suggested that the apparently small diameter is due to specular reflection, so that Pluto is in fact much larger than we think, and all we see is the light of the Sun reflected from a *part* of its surface.

ROTATION. Measurements of the brightness variations of the planet, made in 1955, indicate that the rotation period is about 6 days 9 hours, though this value is naturally uncertain. The variations are due probably to surface features of unequal albedo drifting across the disc because of the rotation, and there can be little doubt that Pluto, unlike the giants, presents a solid surface.

TEMPERATURE AND ATMOSPHERE. Pluto has a mean temperature of —210° C., but the value is naturally higher near perihelion, while the aphelion temperature must be terribly low. A tenuous atmosphere may be retained, but none has so far been detected.

STATUS OF PLUTO. The small size, the strange orbit and the generally anomalous features of Pluto have led to doubts as to whether it should be ranked as a major planet. It is not much larger than **Triton**, and it has been suggested that Pluto is a former satellite of **Neptune** that has been parted from its primary.

Such a theory is interesting, but is difficult to prove or disprove. Further research into the diameter and mass of Pluto may be significant, but is so difficult that it can be carried out only by the world's largest telescopes.

It must be admitted that Pluto is a peculiar world. It was discovered only about thirty years ago, but even in that short time it has proved to be one of the most puzzling members of the solar system. (P.M.)

POLAR REGIONS. The areas near the poles of the axis of rotation of a planet. On the Earth, they are defined as the areas within the Arctic and Antarctic Circles, which are 23° 27′ from the North and South Poles respectively. The inclination of the Earth's axis to the 'upright' in its orbit is 23° 27′, so that at a **solstice** one polar region is bathed in sunlight 24 hours a day, while in the other the Sun does not rise.

The polar regions receive as much sunshine as any other place on the Earth, but most of it continuously near midsummer. The Sun's rays always strike the polar regions rather obliquely, so that the latter tend to be the coldest parts of the globe.

POLARIS. A U.S. Navy surface-to-surface **missile** which may be fired from a submerged submarine. It is a remarkably compact missile, and up to sixteen may be carried by one submarine.

POLE STAR (also known as *Polaris*, or α *Ursae Minoris*). A fairly bright star which happens to be close to the north pole of the **celestial sphere**. Owing to this, it describes only a very small circle in the sky, and its bearing is always close to true North. It is a **binary star**, and one of its components is a Cepheid **variable star**. It is easily found, as it lies in almost a straight line with the 'Pointers' of the Plough or **Great Bear**.

POPULATION, STELLAR. See **Hertzsprung-Russell Diagram.**

PRECESSION. A slow change in the direction in space of the Earth's axis of rotation. It arises from the tendency of the gravitational attraction of the Sun and the Moon to pull the Earth's equatorial bulge into line with this attraction. The Earth behaves like a spinning top whose axis is tilted to the vertical at a fixed angle throughout its 'wobble'.

As a result of precession, the poles of the **celestial sphere** describe circles among the stars; a complete cycle requires nearly 26,000 years. It is pure chance that the pole is presently so close to as bright a star as Polaris; about 2900 B.C. α Draconis was the Pole Star; future candidates for the position are α Cephei and α Lyrae.

PRIMARY. The most massive body in any system of bodies which revolve about their common centre of gravity. The Earth is the Moon's primary; every planet is the primary of its satellites.

The term is used in double-star astronomy to denote the *brighter* star of a pair.

PRIME MERIDIAN. The arbitrary zero of longitude on the Earth's surface. It is defined as the **meridian** passing through the Airy transit circle at the Royal Greenwich Observatory.

PRISM. A glass block having flat surfaces inclined to one another. Light entering through one of the faces is bent by refraction; different colours are refracted by slightly different amounts (see **Refraction**) and the colours are therefore separated, and form a spectrum.

PROMINENCES. Masses of glowing gas projected above the solar chromosphere. See **Sun.**

PROPELLENT. A substance carried in a rocket to be expelled from the motor as a propulsive jet. A few rockets have only one propellent (*monopropellent*) but usually there are two. They may be either solid or liquid. If solid, they are mixed together and burnt *in situ*; if liquid, they are stored in separate tanks and fed into the motor, where they burn to form a gaseous exhaust jet. The chemical reaction which takes place is called oxidation, and the two propellents are the fuel and oxidant.

There is a theoretical maximum *exhaust velocity* attainable with any given pair of propellents; this could only be reached if *all* the chemical *energy* of the combustion were converted into kinetic energy of the molecules of the jet. The highest exhaust velocity achieved so far is about 10,000 ft. per second. If monatomic hydrogen could be stabilized in liquid form, the energy released when it forms molecules containing two atoms each would be sufficient to raise the theoretical maximum to 56,000 ft. per second. But such a fluid would have great risks of explosion attached to it, far more even than other monopropellents.

Nuclear reactors, on the other hand, can make use of almost any chemically inert working fluid as propellent. If ordinary molecular hydrogen is heated to 4,000° C. above absolute zero by such a reactor it can be expelled in a jet with a velocity of 35,000 ft. per second; this is sufficient to propel a single-stage rocket with a mass ratio of three to one into space. There is no reason why the engineering problems posed by this method should not ultimately be overcome. (See also **Rocketry**.)

PROPER MOTION. The continuous movement on the celestial sphere of a star, as seen from the Sun.

From the Earth, the motion of a star generally appears to be along a wavy rather than a straight line, as the observed shift is caused by a combination of proper motion and parallax.

Each star has its own proper motion, which is determined by comparison of photographs

taken at long intervals, or more accurately by recording its meridian passages. The amount of the movement is very small: only 0.3% of stars brighter than the 9th magnitude have proper motions greater than one minute of arc in 600 years. A few stars exceed this value considerably: the record is held by an insignificant star of the 10th magnitude with a proper motion of one minute of arc every six years.

PROTON. A fundamental particle existing in the nuclei of all **atoms**. It has a positive electrical charge and a mass almost equal to that of the hydrogen atom. The number of protons in the nucleus of an atom determines its atomic number and its identity as a chemical element.

PROTON-PROTON REACTION. One of the two principal nuclear processes which provide the energy of normal stars. See **Stellar Energy**.

PROXIMA CENTAURI. The star nearest to the Earth (excepting, of course, the Sun). Its distance is $4\frac{1}{4}$ light years or 25,000,000,000,000 miles. A red dwarf of apparent magnitude 11.3, it is an insignificant member of the multiple system α **Centauri** whose two bright components are relatively close together. Proxima is at an immense distance from these two (it is seen 2° away in the sky) and although it is slowly describing its orbit around the centre of the system it will be a long time before it becomes remoter than the bright pair.

PTOLEMAIC SYSTEM. According to most of the old astronomers, the Earth lay at rest in the centre of the Universe while the heavenly bodies revolved round it at various distances. This system was summed up by Claudius Ptolemaeus (Ptolemy) in his famous 'Almagest', and is thus known as the Ptolemaic System, though as a matter of fact Ptolemy himself was not its originator. (See **Cosmology**.)

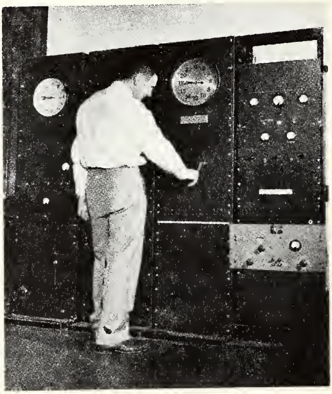
Q

QUADRANT. A form of **sextant**, with a graduated rim forming roughly one-quarter of a circle.

QUADRANTIDS. A **meteor** shower with quite a small orbit; its displays occur on January 3.

QUADRATURE. See **Conjunction.**

QUANTUM. Electromagnetic radiation is not emitted continuously but is always divided into separate small 'packets' of energy named *quanta*. The wavelength of the radiation determines the energy of the quantum, i.e. the size of the packet. One quantum is the smallest amount of energy which can be transmitted at any given wavelength. (See also **Electromagnetic Radiation** and **Photon.**)



A PAIR OF QUARTZ CRYSTAL CLOCKS which automatically transmit standard time signals. (*U.S. Naval Observatory*)

QUARTZ CLOCK. The type of clock at present used by observatories for time determinations of the highest accuracy. It relies upon a small disc of quartz, which when set in vibration oscillates at a particular 'natural' rate with great constancy. The quartz is sandwiched between two metal plates; these are connected to an electrical system which both maintains and counts the vibrations of the quartz disc. The counting mechanism constitutes the 'clock'. Quartz clocks are rather temperamental, and several are generally run together to check one another. Although they are very accurate over short periods – their daily error does not exceed 0.00001 of a second – pendulum clocks are still better time-keepers over periods of a year or more.

R

RADAR. A Radio Detection And Rangefinding system.

With the exception of self-luminous objects such as the Sun or an electric lamp, the human eye can only see things by the light they reflect. For example, we see an aeroplane in the daytime by light which it reflects from, ultimately, the Sun. At night it is invisible unless we direct a searchlight on it. A radar beam is a searchlight, but instead of light waves it emits radio waves each a few centimetres in length. As the eye is not sensitive to radio waves, an aircraft 'illuminated' by a radar searchlight is not directly visible, and a suitable wireless receiver is used to 'see' the plane and advise the operator of its presence. The receiver also detects its direction and distance. The radar beam is turned on and off regularly, and the time which elapses between turning it on and the arrival of its reflection is a measure of the distance of the aircraft. In the same way one can estimate the distance of a wall or the depth of a well by the time it takes to obtain the echo of a sound from it.

Many radar equipments employ a beam which sweeps round the sky or the horizon, and the received reflections are plotted on a screen by a rotating streak which builds up a map-like picture of the scanned area. Metallic objects show up best on radar screens, but rainclouds, and certain land formations and a variety of other solid objects also give radar echoes.

RADIAL VELOCITY. The speed of approach or recession of a body from the point of observation.

Radial velocity with respect to the Earth can be determined by measuring the **Doppler shift** between lines of the same elements in the spectra of the star and of a laboratory source on the Earth. It is reckoned to be positive if the star is receding, negative if it is approaching.

RADIATION, ELECTROMAGNETIC. See **Electromagnetic Radiation.**

RADIATION BELT. See **Van Allen Belts.**

RADIATION PRESSURE. The force exerted by light or other **electromagnetic radiation** in a direction away from its source.

The Sun's radiation pressure is of special interest, as it has observable effects. The pressure is small for any but tremendously intense radiation, and for large bodies its force becomes entirely insignificant compared with the gravitational force acting in the opposite direction. However, radiation pressure is proportional to the illuminated area of a body, while gravitation depends on the mass, and the latter decreases more rapidly than surface area with decreasing size. Consequently, for bodies below a certain critical diameter the radiation pressure has the upper hand, and such particles are repelled from the Sun. This phenomenon is responsible for the tails of comets. The particles in those tails must be below the limiting size of about 0.0015 millimetres but more than 0.0007 mm. across, at which value radiation pressure again becomes ineffective as the waves constituting the radiation do not 'break' on so small an obstruction and so exert no pressure on it.

RADIAN. A unit for the measurement of angles, equal to about 57 degrees. An arc of a circle whose length is equal to the radius of the circle subtends an angle of one radian at the centre. $360° = 2\ \pi$ radians.

RADIANT, METEOR. The point in the sky from which the meteors in a particular shower seem to emanate. See **Meteor**.

RADIO ASTRONOMY. Until recently, astronomical research has been carried out with telescopes and other instruments receiving light waves emitted by the stars in the visual part of the **electromagnetic spectrum**. Auxiliary instruments, such as photo-electric cells and photographic plates, have extended these studies somewhat beyond the visual limits into the infra-red and ultra-violet regions, but great extension is impossible because of the absorption caused by water vapour and fine dust in the Earth's atmosphere. There was, until lately, little astronomical interest in a second, more extensive gap or window in the atmosphere.

This other gap exists in the radio wave region. At its short-wave end it also is limited by atmospheric absorption at a wavelength of a few centimetres, and at the long-wave end by reflection from the Heaviside layer at a wavelength of about twenty metres. Any radio wave generated in space within this waveband can be received on the Earth.

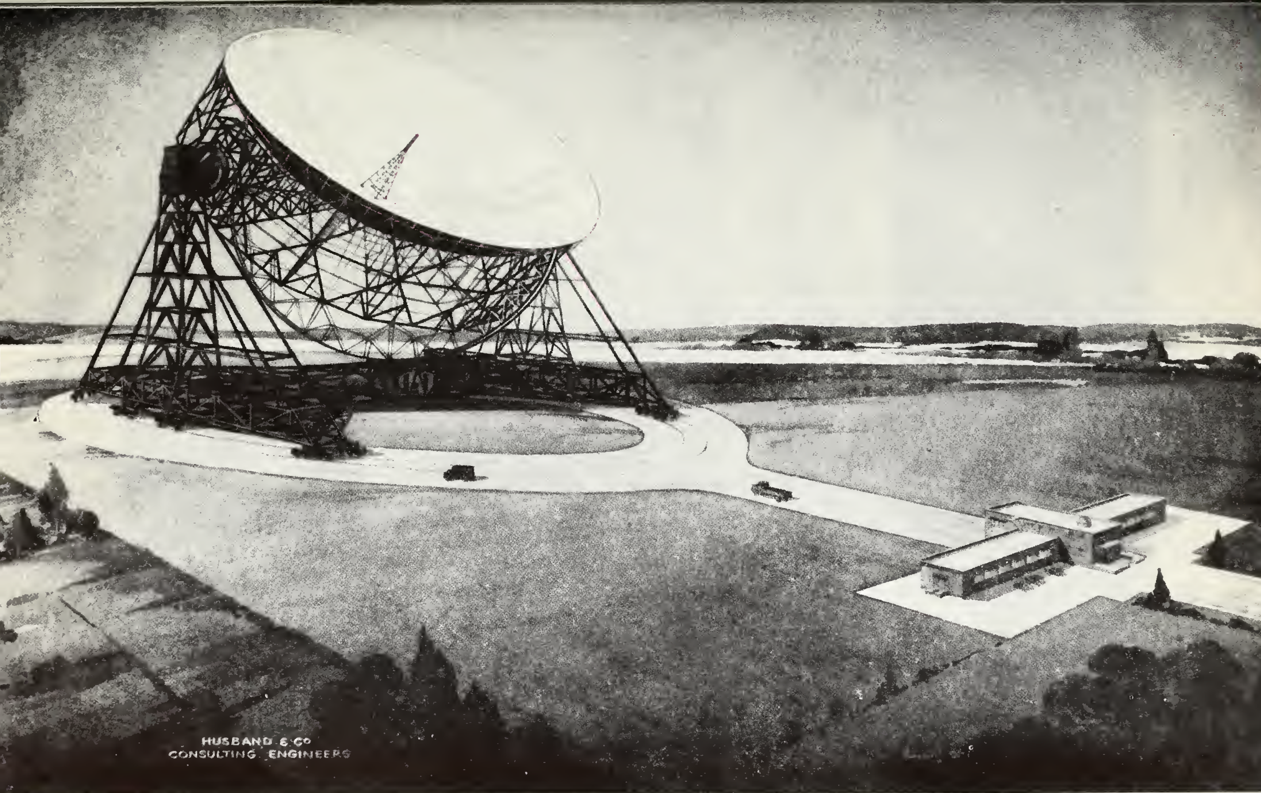
RADIO WAVES FROM SPACE. Such radiation was first detected in 1931. The signals were strongest from the Milky Way, and were roughly proportionate in strength to the concentration of stars in the direction in which the radio receiver was pointing. On the other hand, no signals emanated from the bright stars or other prominent features visible in telescopes. This led to the view that the signals were being generated in the very rarefied hydrogen gas in interstellar space.

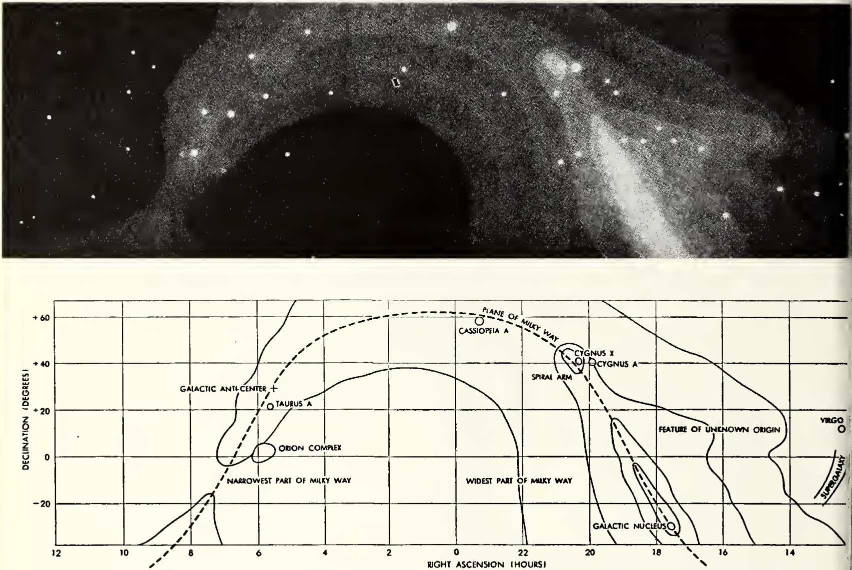
THE DISCOVERY OF RADIO STARS. In 1948 it was found that at least some of the radio waves were coming from discrete or localized sources in space, subsequently called *radio stars*. The two most intense of these sources were in the constellations Cygnus and Cassiopeia; but although both lay in densely populated stellar regions there were no particular visual objects to which the radio emissions could be attributed.

Later many other, less intense, radio stars were discovered and there seemed to be no correlation with any recognized class of star. The belief arose that we were dealing with a new type of body in the heavens, dark or only faintly luminous, but emitting powerful radio waves; moreover, a type of frequent occurrence and distributed throughout the Galaxy in a manner similar to that of the common stars. In 1950 the **Andromeda Nebula** was found to radiate in the same way as our Galaxy. Emissions from many other nebulae have since been detected, and it is now accepted that radio stars similar to those responsible for the emission in the Milky Way system must be widely dispersed throughout the Universe.

IDENTIFICATION OF RADIO STARS. In the last few years there has been close co-operation between astronomers using radio telescopes and those with the big optical telescopes in America, in an effort to relate radio sources to visible objects. Although nearly two thousand of the radio sources have now been located, and in many cases their sizes and shapes measured, remarkably few correspond with visual sources. We are, however, now certain of one connection. Occasionally a star blows up – it becomes a **supernova**: the processes which generate energy inside the star get out of hand and Nature gives a replica on a really stupendous scale of a hydrogen bomb explosion. Instead of a few pounds of hydrogen, the whole star goes up. Only three such explosions of stars in the Milky Way have ever been recorded. The most famous of these occurred nine hundred years ago, and the remains of the star can still be seen as an enormous cloud of tremendously hot gas rushing into space at a rate of three million miles an hour. This object – the **Crab Nebula** – has now definitely been established as one of the strongest radio sources. The other two supernovae are also radio sources, although very much weaker. These connections are of extreme interest, but it seems unlikely that supernovae can account for more than a few of the sources in the Galaxy.

THE GREAT RADIO TELESCOPE AT JODRELL BANK near Manchester.
(*Husband & Co., Consulting Engineers*)


HUSBAND & Co
CONSULTING ENGINEERS



THE RADIO SKY as it would appear to our eyes if they were sensitive to radio waves instead of light. The bright patch on the right lies in the direction of the centre of our galaxy and is unobscured by the dark nebulae that absorb so much of the visible part of the spectrum. Few of the individual radio stars correspond to visual objects. (*Kraus, Scientific American*)

A few years ago, the intense source in Cassiopeia was identified with a faintly luminous cloud of gas, spread out over a volume large compared with a star. Some of the gas is in extremely violent motion, and the generation of radio signals must be connected in some way with this motion. Two or three similar objects have been located in the positions of less intense radio stars, and this type of diffuse gaseous agglomeration may be responsible for many of the radio stars. The objects are so faint that they can only be photographed with difficulty, using the world's biggest telescope, and yet they generate powerful radio signals. Some attempt has been made to link them with very old supernovae; on the other hand, they may be stars in the very early stages of formation.

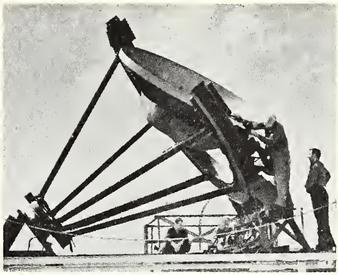
THE COLLISION OF NEBULAE. Perhaps the most remarkable identification so far made is that of the second most intense radio source in the sky, which lies in the constellation Cygnus. The early efforts to link up this source with a visible object led to no result. About five years ago, however, the region of the source was photographed with the Palomar telescope. The plates yielded the usual large number of faint stars and nebulae, but in the position of the radio source there was something new – two great nebulae in a state of collision. This celestial catastrophe is taking place at an enormous distance – a hundred million light years – from us. Why such a collision should result in the emission of powerful radio signals is unknown. The generation of the radio waves must be occa-

sioned by the turmoil created in the gas and the dust as the two nebulae pass through one another, as the stars are so far apart that their collisions must be rare.

The establishment of the connection between this faint object and the powerful source of radio emission in Cygnus carries with it one of the most surprising implications in the whole of radio astronomy. In some regions of space the galaxies are closely packed in clusters, and in these we find, perhaps, a thousand galaxies separated by only thirty thousand light years. Calculations indicate that the chances of a collision are considerable. In the case of the Cygnus collision we receive a powerful radio signal, although the two colliding nebulae are so distant; even if the galaxies were so far away that they could not be identified by *optical* telescopes, it would still be possible to detect their emission with the *radio* telescopes.

THE SPECTRAL LINE EMISSION FROM NEUTRAL HYDROGEN GAS. A great deal of attention has lately been given to another type of radio emission from space, generated in the neutral hydrogen gas in the Milky Way on a single wavelength of 21 centimetres. This is a spectral line emitted when the spin of the nucleus in the ground state of a neutral hydrogen atom reverses (see **Spectroscopy**). The hydrogen clouds are tens of thousands of light years distant and contain only about one hydrogen atom per cubic centimetre. In an undisturbed atom a change of spin is only likely to happen once in about eleven million years. It seems, however, that the atoms in their random motions collide every fifty years, and in a collision there is a one-in-eight chance that this transition will occur.

The hydrogen clouds are in motion relative to the solar system and this 21 centimetre spectral line consequently shows a **Doppler** shift in its frequency. This shift has made possible the study of the motions of the hydrogen clouds in the Milky Way, which are obscured from the view of the optical telescopes by dust. Whereas a few years ago there was a good deal of speculation as to the exact structure of the Milky Way system, these uncertainties have been very largely removed. In a few years we have acquired a remarkably complete description of the spiral formation of our Galaxy. The extension of this work to the extragalactic nebulae by the use of larger radio telescopes is eagerly awaited.



The mounting of a small radio telescope on the roof of the U.S. Naval Research Laboratory, Washington. The mechanic is adjusting the electric motor which turns the telescope in declination.

THE DETECTION OF METEORS BY RADIO. Many millions of meteors enter the Earth's atmosphere every day; but their trails last so short a time that the accurate measurement of the velocity and direction by visual means is difficult. Photographic techniques are accurate, but unfortunately the interesting events are often obscured by cloud or bright moonlight. However, a part of the energy of the meteor is used in ionizing the air through which it passes, and the resultant column of electrons reflects radio waves. In the last few years, radio echo techniques for the study of meteors have been perfected and the individual orbits of several hundred meteors a day can be measured with a single apparatus.

A great advantage of the radio echo technique is that the study of meteors can be carried out without hindrance by cloud or daylight. The discovery that great streams of meteors are active in the summer daytime is one of the most dramatic results of this new technique. These daytime meteor streams move around the Sun in orbits of only a few years' period. One stream is almost certainly moving in the orbit of Encke's Comet, but for

the remainder no relations with other bodies in the solar system have been established.

Radio investigation of meteors can be used to measure the physical and meteorological conditions in the atmosphere 50 to 120 kilometres above the Earth's surface. Pressures, temperatures, winds and other topics come within the province of these investigations (see also **Meteor**).

STUDIES OF THE SUN. The **Sun** itself emits radio waves. These appear to originate in the corona, but when a spot appears on the surface much more intense waves are emitted, and these are known to originate in the region of the spot itself. Occasionally, when the spot activity is considerable, a solar flare forms in the region of a group of spots. Flares have much influence on the Earth's ionosphere; one result is the appearance of aurorae. Radio investigations of the Sun and the ionosphere are being actively pursued, and the surprisingly high temperature of the Sun's corona derived by optical methods has been confirmed.

RADIO TRACKING. Ever since the first **artificial satellites** were launched, radio telescopes have played an important part in tracking them, in receiving signals from them and in sending signals to the satellites to activate part of their instrumentation. The range over which signals from a space vehicle can be received and disentangled from the background of random radio noise depends on the strength of the transmitter and the diameter of the paraboloid bowl or 'dish' of the radio telescope. Transmitter power is limited by the payload weight available for the transmitter and its power source. The need for large bowls is made clear by the accompanying table, which shows that even Jodrell Bank cannot receive the *Pioneer V* **Venus Probe** on the outer part of its journey.

Transmitter Power	Minimum Bowl Size for Reception over a Range of:	
	50m. miles	*200m. miles*
100 watts	225 ft.	900 ft.
500 watts	100 ft.	415 ft.
1 kilowatt	60 ft.	280 ft.

NEW TELESCOPES. The ever-increasing demands on the time of radio telescopes and the need for coverage of the whole sky at any time of day or night are being partly met by the new 600 ft. bowl in West Virginia, and that of 210 ft. in Australia.

Radio astronomy is one of the youngest of the sciences, but it has already drawn for us the outlines of an entirely new view of the Universe. (A.C.L.)

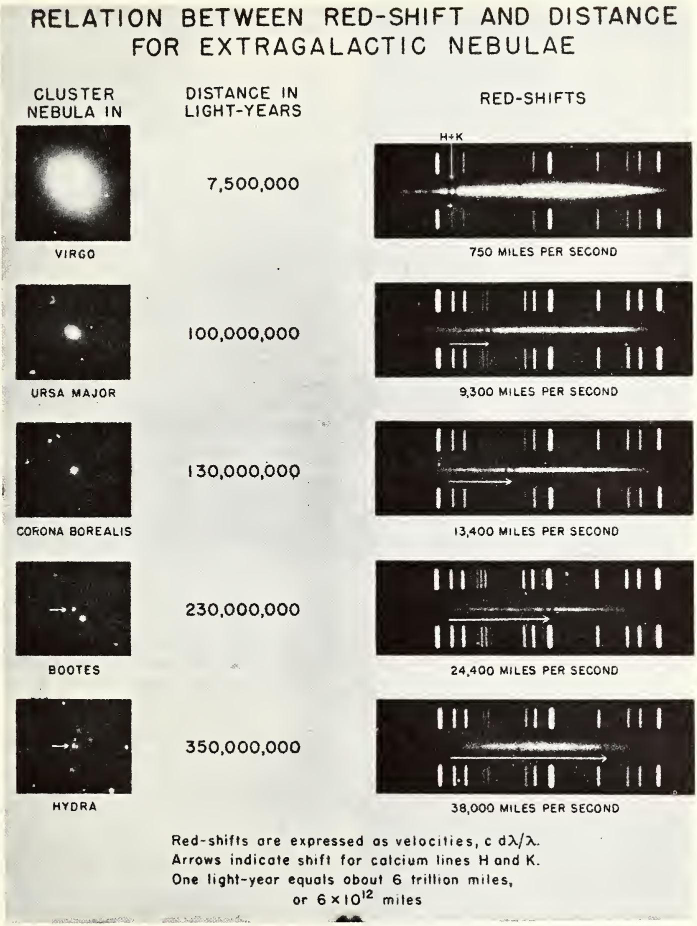
RADIO STAR. A well-defined celestial source of radio waves. See **Radio Astronomy.**

RADIO TELESCOPE. A wireless receiver, often with huge aerials, used for **Radio Astronomy.**

RADIUM. A chemical element, the nuclei of whose atoms contain 88 protons. The nuclei are unstable and undergo radioactive decay, which is accompanied by the expulsion of **helium** nuclei (α particles), very fast **electrons** (β particles) and radiation more penetrating than X-rays (γ rays); the radium is slowly turned into lead during the process.

RAKETENFLUGPLATZ, BERLIN. The first rocket proving grounds, where many valuable experiments were conducted between 1930 and 1933 by the *Verein fuer Raumschiffahrt.*

RED SHIFT. The displacement of spectral lines towards the red end of the spectrum, an invariable feature of the spectra of **extragalactic nebulae.** This is interpreted as a **Doppler** shift, indicating a recession of the



The above plate illustrates the shift of spectral lines towards the red end of the spectrum, which is greatest for the most distant sources. If it is a true Doppler shift, it must be due to the speeds with which the galaxies recede from us and from each other – the expansion of the Universe. (*Mt. Wilson – Palomar*)

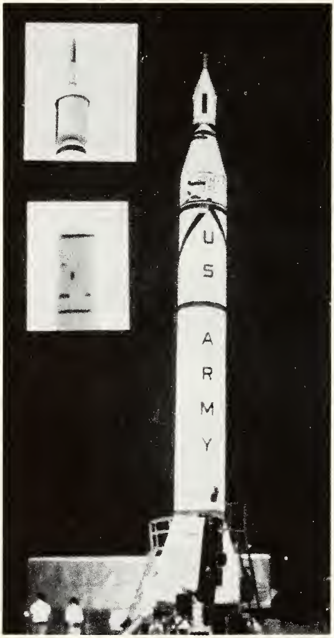
galaxies. Its amount is proportional to the distance of the galaxy concerned.

RED SPOT. The only feature upon Jupiter which is regarded as semi-permanent. It was seen in 1831, but first became prominent in 1878, when it developed into a red-coloured ellipse 22,000 miles long and 7,000 miles wide. Since then it has been under fairly continuous observation, though it is no longer prominent and the brick-red colour has faded.

The nature of the Spot is uncertain. It has been attributed to some kind of volcanic eruption, but there is no proof of this, and all that can be said with certainty is that it is a semi-solid body or group of bodies lying in the upper region of Jupiter's atmosphere. It is associated with the *Red Spot Hollow.* During the period of the South Tropical Disturbance, 1901–40, there were marked interactions when the Disturbance overtook and passed the Spot. (See **Jupiter.**)

RE-ENTRY. The return into the Earth's atmosphere of a space vehicle or missile. A body re-entering at high speed is liable to be partly or wholly vaporised by the heat generated by atmospheric friction, as if it were a meteorite. This may be prevented by slowing it down with retarding rocket pulses, by providing it with heat shielding, or by the technique of **braking ellipses.**

REFLECTING TELESCOPE. A telescope which uses a curved mirror to form images of distant objects. (See **Telescope.**)



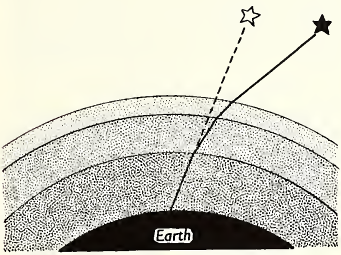
Upper left: JUPITER-C prior to test firing with a re-entry nose-cone which was later recovered. The insets show a different nose-cone carrying an Explorer satellite, and an experimental Thor nose-cone. The flattened nose-cone takes the brunt of the air friction on re-entry; part of it will be burnt away, and another part—the 'heat-sink'—will absorb most of the heat conducted inwards from the leading surfaces and so protect the inner mechanism. Heat sinks may be jettisoned when the vehicle has slowed down.

Lower left: Jupiter nose-cone containing Monkey Able and Monkey Baker in the sea after successful re-entry.

REFRACTING TELESCOPE. A telescope which uses a system of lenses to form images of distant objects. (See **Telescope.**)

REFRACTION. The change in the direction of a ray of light as it passes from one transparent substance into another.

If the boundary between the substances is sharp, as in the case of a glass lens in air, the path of the light is bent through a definite angle at the surface. Where the transition is gradual, e.g. from a dense layer of air into a more rarefied one, the light path is bent into a curve.



Light from a star is bent as it passes from one layer of air into a lower, denser one. We 'see' a celestial object in the direction from which its light appears to come to the point of observation. The layers of air are not, of course, distinct as in the diagram.

The twinkling of stars is due to irregular refraction by moving streams of air of different densities, and is a serious handicap to astronomers. This is discussed under **Seeing.** Atmospheric refraction also affects the apparent **altitude** of objects above the horizon, and in extreme cases gives rise to mirages.

Most light-sources emit light which consists of a mixture of wavelengths (i.e. colours), and shorter wavelengths are refracted more than longer ones. This may be used to separate the constituent colours of a beam of light to form a spectrum, of which the rainbow is a natural example. (See also **Prism,** and **Lens.**)

REGULUS. A surface-to-surface winged tactical **missile** of the U.S. Navy, named after a bright star in the constellation *Leo.*

RELATIVITY, THEORY OF. A theory, now universally accepted, proposed by Albert Einstein to account for and predict the results of certain physical observations which could not be satisfactorily explained by earlier theories.

The main stumbling block to the old system of physics was an experiment made in 1887 by Michelson and Morley to demonstrate once more that the Earth moved. It was argued that light was a wave motion, and that there must therefore be some medium in which the waves could travel, in the same way as sound waves need some medium, such as air, in which to propagate. As light seemed to travel everywhere in space, the physicists of the 19th century postulated an intangible aether, pervading the whole of space. There was every reason to suppose that light travelled at the same velocity in the aether whatever the motion of the source; and that the Earth's velocity relative to the aether could be found by measuring the apparent velocity of light in different directions on the Earth. Consternation reigned when the experiment was performed, for it showed beyond doubt that *the Earth was always at rest in the aether!* This result struck at the very foundations of the physics which had stood for so long that its validity was accepted without question. Many scientists attempted to reconcile the experimental result with theory, but in vain.

Einstein, with characteristic irreverence for 'established' physics, and realizing the fundamental importance of the Michelson-Morley experiment, used its result, stated in the form that *the velocity of light appears the same to all observers*, as the fundamental postulate of a new theory; he used also the axiom that *it is impossible to detect absolute rest in space*, i.e. that all velocities must be measured with respect to some other body. On these two foundations Einstein erected his Theory of Relativity. The first instalment, the Special Theory, published in 1905, showed that distance and time were interrelated, and that extreme velocities comparable with that of light could not be added according to the simple rules governing the addition of everyday velocities. Other results were that no

velocity greater than that of light could be observed; that the mass of a body increases with its velocity, and that mass and energy are equivalent. The latter relation is written

$$E = mc^2$$

(energy = mass × square of the velocity of light.)

The theory aroused little interest at first, as there seemed little prospect of obtaining velocities high enough to test its validity: at low velocities relativistic theory gives results which are virtually indistinguishable from those of 'classical' mechanics. Also, no-one had ever witnessed the interconversion of mass and energy; in all operations mass and energy had separately been conserved. However, the second instalment of the theory, the General Theory, published in 1916, had more immediately tangible results. The General Theory incorporated gravitation into relativity theory, proved that it was identical with acceleration and showed that orbits should undergo a continuous precessional motion, such as that of the perihelion of the orbit of Mercury; it gave the exact amount of this precession, removing an anomaly which had long puzzled astronomers. It showed also that light rays should be deflected in passing through a gravitational field. Here was a prediction which could be verified: at a total eclipse of the Sun stars can be seen shining close to the Sun's limb, and the theory predicts that, owing to deflection of the starlight by the Sun's gravitational field, the stars should appear to be shifted outwards slightly. A successful expedition to Brazil to observe the eclipse of May 29, 1919, confirmed this prediction completely.

Many further confirmations of the theory of relativity have since been forthcoming. Light which is emitted from a source in a very strong gravitational field, such as that of a white dwarf star, is found to be slightly reddened as expected by the theory. The increase of mass with velocity is a very important factor which has to be taken into account in designing machines for use in nuclear physics research. The relation between mass and energy has been convincingly demonstrated in the atomic bomb, which obtains its great energy by the annihilation of part of the matter of which it is made.

Except in a few instances and where very great velocities are concerned, the Newtonian law of gravitation and 'classical' mechanics remain excellent approximations to the truth; the theory of relativity is necessary to explain the shortcomings in the older theories only when they are applied to velocities and conditions outside the ordinary range of human experience. (R.G.)

RESOLVING POWER. The ability of an optical system to distinguish separately two closely spaced sources of light. (See **Telescope.**)

RETROGRADE MOTION. Orbital motion within the solar system in a direction opposite to that of the planets, i.e. clockwise as seen from north of the ecliptic. Halley's Comet, some of the satellites of the giant planets, and certain meteor streams have retrograde motion, but the vast majority of bodies in the system revolve in *direct* orbits.

RIGHT ASCENSION. The sidereal time that elapses between the meridian passage of the First Point of Aries and of a celestial body is that body's Right Ascension. It corresponds to longitude on the Earth. See **Celestial Sphere.**

ROCHE LIMIT. If a satellite approaches its primary within a certain critical distance, tidal forces shatter it into fragments. This critical distance is the Roche Limit, and is 2.44 radii of the primary from its centre. It only holds for satellites which are held together chiefly by their own gravitation fields and not by cohesion of their materials and therefore does not apply to artificial satellites, or to such small bodies as Phobos, which is only just outside the Roche Limit.

Saturn's ring system is entirely within the Roche Limit, measuring 2.30 radii of Saturn: very possibly it has resulted from the tidal disruption of one or more satellites. The closest of Saturn's satellites, Mimas, is 3.11 radii from the centre of the planet.

ROCKET INSTRUMENTATION. During the all-too-brief moments of a rocket's flight, an enormous amount of information

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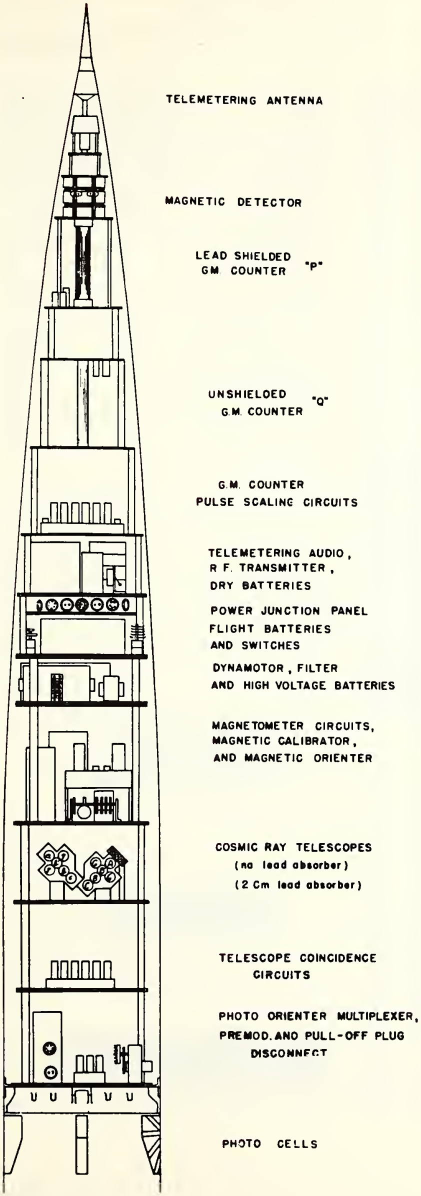
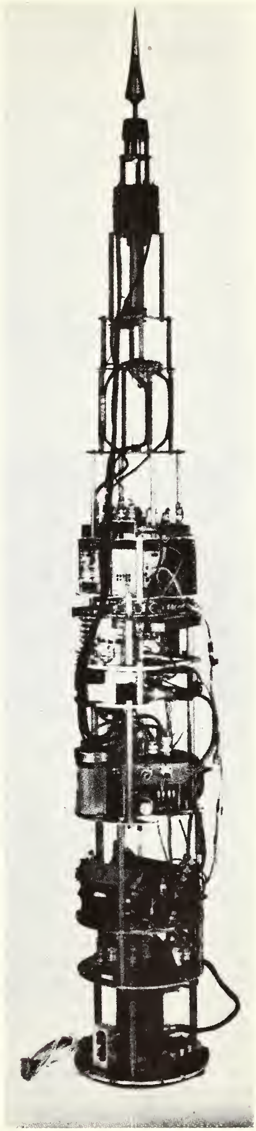
Opposite: AN AEROBEE NOSE-CONE INSTRUMENTATION.

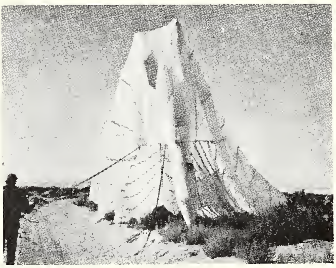

TELEMETERING ANTENNA
MAGNETIC DETECTOR
LEAD SHIELDED
GM COUNTER "P"
UNSHIELDED
G.M. COUNTER "Q"
G.M. COUNTER
PULSE SCALING CIRCUITS
TELEMETERING AUDIO,
R F. TRANSMITTER,
DRY BATTERIES
POWER JUNCTION PANEL
FLIGHT BATTERIES
AND SWITCHES
DYNAMOTOR, FILTER
AND HIGH VOLTAGE BATTERIES
MAGNETOMETER CIRCUITS,
MAGNETIC CALIBRATOR,
AND MAGNETIC ORIENTER
COSMIC RAY TELESCOPES
(no lead absorber)
(2 Cm lead absorber)
TELESCOPE COINCIDENCE
CIRCUITS
PHOTO ORIENTER MULTIPLEXER,
PREMOD. AND PULL-OFF PLUG
DISCONNECT
PHOTO CELLS



AEROBEE A-11

must be collected. Many measurements are made by instruments in the rocket, and the readings of each must be transmitted to Earth at frequent intervals. The recordings of the instruments in the rocket are relayed by radio; to save power, many instruments are connected in turn to the same transmitter, whose output is received and 'unscrambled' by electronic machines at a ground station. A master timing signal is superimposed on all the records.

Rocket-borne instruments must respond quickly to their rapidly changing environment; they must be capable of being checked during flight lest the unusual conditions alter the electrical circuits' characteristics; and they must be reliable, or months of preparation are wasted.



A research missile recovered by parachute.

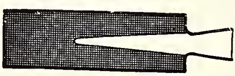
The most important measurements to be made during any rocket flight are those relating to its position and orientation in space; without these the others become almost worthless. The conditions in the atmosphere surrounding the rocket – its pressure, temperature, density – can be measured, although the difficulty of obtaining reliable values from a fast-moving rocket are considerable. Other readings which have been taken include those of ozone concentration, cosmic ray intensity, sky brightness and airglow, magnetic field, and ionization, and physiological reactions of animals.

ROCKETRY. A rocket is a jet-propelled vehicle, intended to travel above the Earth's surface, which contains within itself all the material for the production of the jet. The expulsion of the jet in one direction causes a recoil of the rocket termed the *thrust*. No air is involved in the production of this force, and the thrust is therefore maintained even when the jet is discharged into a vacuum.

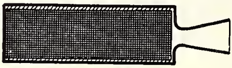
A rocket motor is essentially a tube in which solid or liquid **propellents** burn, and the resulting gas is ejected at one end. The propellents release a large amount of heat energy, so the exhaust gas is very hot and is usually at a pressure of between twenty and thirty atmospheres. A nozzle allows the gas to expand and thereby change the heat energy into energy of motion, so that it is ejected from the rocket at high velocity. The speed of ejection of the gas depends on its temperature before it enters the exhaust nozzle.

Rocket motors can be divided into two broad classes: solid propellent and liquid propellent.

SOLID PROPELLENT ROCKETS are much the less complicated. The propellent tank and the combustion chamber are one and the same compartment: for instance, a gunpowder rocket has a solid mass of propellent hollowed out into a cone-shaped combustion chamber. When ignited, the gunpowder burns only on the inner surface, and combustion proceeds until all the propellent has been converted into hot gases, which escape through an



GUNPOWDER ROCKET



RESTRICTED BURNING

UNRESTRICTED BURNING

expansion nozzle and in doing so are accelerated to supersonic velocity.

Modern solid propellent rockets use smokeless powders such as cordite. For 'unrestricted burning' rockets the cordite is extruded under pressure through dies which shape the surface of the charge so that burning can take place over a large area and not just at one end or in a hollow cone as in the early gunpowder rockets.

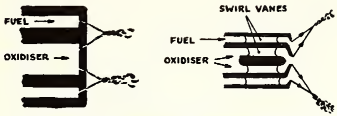
The 'restricted burning' rocket uses a charge which completely fills the inside of the tube. Between the charge and the walls of the tube an inhibitor is used to prevent the passage of the flame. On ignition, the charge burns on the face only and continues to do so until it has all been consumed, like a cigarette. Plastic propellents are often used because they do not deteriorate with storage.

Solid propellent rockets find extensive use as boosters for missiles and research rockets, as the main power plants of small guided missiles, and for the assisted take-off of aircraft.

LIQUID PROPELLENT ROCKETS. The simplest type makes use of a 'mono-propellent', a single liquid which can be made to break up chemically with a considerable release of energy in suitable circumstances; but mono-propellents are often unstable, and sometimes explode accidentally. An example of a mono-propellent is hydrogen peroxide. It is decomposed in the 'combustion' chamber to give superheated steam and oxygen.

Most rocket units employ two propellents: a fuel and an oxidant. The oxidant is often liquid oxygen, nitric acid or hydrogen peroxide; examples of fuel are petrol, alcohol, aniline and hydrazine. Some pairs of propellents ignite spontaneously when they come into contact in the combustion chamber; some do not. Self-igniting propellents have one disadvantage in that spillage or leaks are very dangerous.

There are several possible methods of feeding the fuel and oxidant from the storage tanks into the combustion chamber. One is to pressurize the tanks with some inert gas, so that when the valves are opened the liquids are forced out; but in the case of large rockets and aircraft power plant, where the duration of thrust may be considerable, pressurized tanks are not acceptable. Pump feeds are



Two types of propellent injectors. Left, an impinging jet device; right, impinging conical sheets.

employed, and the extra weight of the pumps is offset by the saving in the weight of the propellent tanks themselves because, not having to withstand high internal pressures, these need not be so strong. The pumps are normally operated by a turbine; this is driven by gases from the decomposition of concentrated hydrogen peroxide or from combustion of the propellents themselves. In the latter case it is necessary to cool the evolved gases before they are applied to the turbine blades.

When the liquids enter the combustion chamber they have to be burned with maximum efficiency. Special injectors ensure that they are finely atomized and intimately mixed in the correct proportions. Some injectors rely upon simple impinging jets, others on multiple sprays or on impinging cones of liquids.

In addition to feeding and mixing the propellents, the injectors are often designed to give a controlled sequence of injection. Build-up of one of the propellents in the chamber before the other arrives must be avoided or a damaging explosion may take place. Again, it is inadvisable to start the motor with the propellents being injected at the full operating pressure, and a two-stage build-up of pressure is used in several designs.

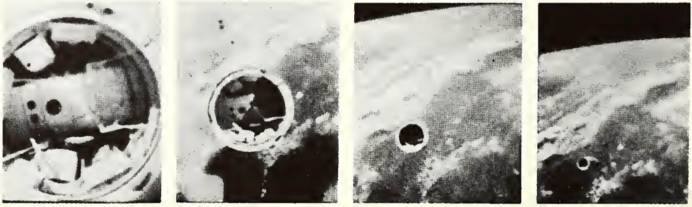
When the propellents burn inside the combustion chamber, extremely high temperatures are developed and some method of cooling the motor is essential. Early motors made use of one of two simple methods. The first was christened the 'heat sponge'. In effect the motor consisted of a bulky mass of metal capable of absorbing most of the heat transmitted to the motor walls during the firing without becoming too hot. Obviously this method is only practical for motors which have short firing times. The second method was to use a combustion chamber lined with material of poor conductivity, so that the heat transmitted to the structure

Left: AN OPTICAL ROCKET-TRACKING TELESCOPE. The operator looks through the guiding telescope and steers the apparatus from controls at his chair, while a ciné-film is taken through the main telescope, a reflector.

would be minimized. Difficulties arose owing to the different expansions of the liner and the metal motor wall, and because shocks in the motor could break the brittle material and cause it to flake from the metal. This method has been considerably improved, and is used in a number of short-life liquid propellent units.

It was, however, *regenerative cooling* which made really large rockets practicable. In this system one of the propellents acts as a coolant and flows round the combustion chamber and nozzle in the space between the double walls before entering the chamber. Heat which would otherwise be lost is carried back into the combustion chamber, and at the same time the coolant keeps the temperature of the chamber walls at an acceptable value. In some motors, supplementary injection of coolant takes place from a series of orifices at strategic positions in the combustion chamber and nozzle to form a cool layer of gases next to the metal wall; this is known as *film cooling*. A further development is to make the walls of the combustion chamber of porous material, so that as the coolant flows round them some seeps through to the inside. Much of the heat which would otherwise reach the wall is used to boil the coolant as it seeps into the chamber. This is *transpiration cooling*.

The final velocity reached by a rocket when all its propellents have been ejected depends upon the **exhaust velocity** and **mass ratio**; the theoretical value cannot be quite achieved by rockets fired from the Earth owing to **gravitational loss** and **air resistance**.

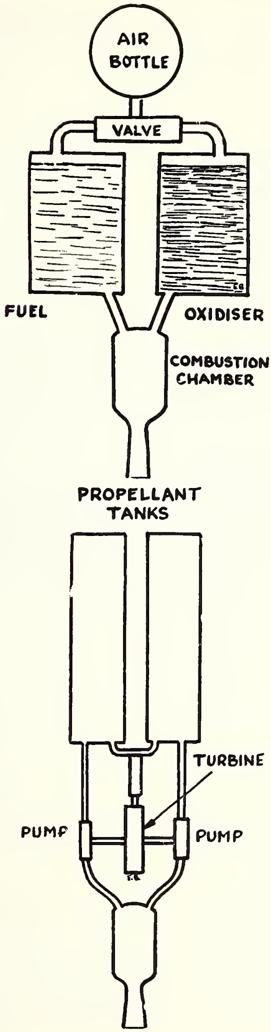


SEPARATION OF A NOSE CONE. This sequence was photographed by a camera in the after part of a re-entry nose cone; the camera was ejected from the cone in a capsule and recovered separately. The first frame shows the interior of the Thor carrier rocket immediately after separation at 125 miles. In the succeeding frames it is seen ascending behind the faster-rising nose cone.

A large effective mass ratio can be obtained by the use of the step principle, i.e. by multi-stage rockets. These compound vehicles consist of several rockets or 'stages' mounted on top of each other in order of decreasing size. The first stage lifts the entire assembly to a moderate height; when it is expended it is jettisoned and the second stage starts firing automatically and carries the remainder of the vehicle further along its trajectory at increased speed. Three or four stages are often used in this way to impart a very high final velocity to the last stage, which alone contains the payload. Theoretically the step principle may be carried as far as one likes, but in practice even extremely small final stages require very massive earlier stages, and the complexity of construction and control of multi-stage rockets makes them extremely costly and less reliable than simpler designs.

The problems of bringing rockets back into an atmosphere from space are discussed under **re-entry**.

Experimental work is proceeding on three other methods of rocket propulsion: the harnessing of nuclear energy to rocket motors ejecting **plasma**, **ion rockets**, and the use of **radiation pressure** of sunlight acting on large *photon sails*. Ion rockets could have vast exhaust velocities but would accelerate very slowly, and are therefore not suitable for early stages of a step rocket. Photon sail vehicles are not rockets in the true sense, since they are not propelled by the recoil from the ejection of matter at high speed; radiation pressure is a weak source of energy but one that is perpetually available to a vehicle within the solar system, and it may one day find some special application. Nuclear energy opens up the brightest prospects; it is only a matter of time before nuclear reactions can be controlled inside a sufficiently light structure that can withstand the high temperatures involved.



Propellent feeds for liquid propellent rockets may consist of simple three-tank system (*top*) in which an inert gas under pressure forces the liquids into the combustion chamber. Alternatively gases from the combustion of the propellents can drive a turbine linked to pumps (*bottom*).

ROCKOON. A device consisting of a rocket suspended from a balloon which is carried to high altitude before the rocket is launched. See **Farside Rocket**.

ROTATION. In astronomy, the spin of a body about an axis through its centre of gravity. It must not be confused with *revolution*, which is a movement in an orbit about an external point or object.

RR LYRAE. The star which gives its name to a class of variable stars. All RR Lyrae variables are found to be of the same absolute magnitude, just about zero. (See **Variable Stars** and **Stars, Distances and Motions**.)

S

SAROS. A cycle first used by Chaldean astronomers to predict eclipses. An eclipse of, say, the Sun can only occur if the Moon is New and near a **node**; otherwise it passes 'above' or 'below' the Sun. After 18 years and $10\frac{1}{3}$ days (or $11\frac{1}{3}$, depending upon leap years) the Moon is again New and the Sun is again in virtually the same position with respect to the node. The conditions for eclipse hence recur after this period or Saros. By chance, the distance of the Moon also happens to be almost the same at the beginning and end of a Saros, and so eclipses of successive cycles are similar in type – annular or total.

Owing to the odd third of a day in the Saros, succeeding corresponding eclipses are seen in different longitudes, shifting one-third of the way round the Earth at each return; hence an eclipse recurs at the same place only at intervals of three Saros cycles. (See also **Eclipse**.)

SATELLITE. Most of the major planets are accompanied by one or more satellites. So far as is known at present, the Earth has one satellite (the Moon); Mars two, Jupiter twelve, Saturn nine, Uranus five and Neptune two. A satellite of Venus was reported periodically during the 15th and 16th centuries, but is definitely non-existent, and this applies also to a tenth satellite of Saturn, Themis, reported in 1904.

Of these 31 satellites, the only one known to possess an atmosphere is Titan, the sixth member of Saturn's family, which is surrounded by a tenuous mantle composed chiefly of methane. Titan has a diameter of 3,500 miles, and is the largest satellite in the solar system. It has, however, only 1/20 the diameter and 1/4700 of the mass of its primary, Saturn, whereas the Moon has $\frac{1}{4}$ the diameter and 1/81 the mass of the Earth.

The origin of the satellite systems is uncertain, but it has been suggested that the smaller bodies – both satellites of Mars, Jupiter VI to XII, Phoebe in Saturn's system and Nereid in Neptune's – may be captured **asteroids**.

Future research may result in the detection of additional satellites, particularly with regard to the four giant planets. (See tables under **Solar System**.)

SATELLITE, ARTIFICIAL. See **Artificial Satellite**.

SATURN is the second of the giant planets. In size and mass it is inferior only to Jupiter, and even at its tremendous distance from the Earth – never much less than 740 million miles – it appears a conspicuous object. When at its brightest, the magnitude is —0.2, so that Saturn is outshone only by four planets (Mercury, Venus, Mars and Jupiter) and two stars (Sirius and Canopus).

Saturn is without doubt the most beautiful object in the heavens. A moderate telescope will show the ring-system well, and the planet presents a spectacle that is not only unrivalled, but unique.

ORBIT. The perihelion and aphelion distances from the Sun are 835 and 938 million miles respectively, giving a mean value of 886 million miles. The orbital eccentricity is 0.056, slightly greater than that of Jupiter, and the inclination is 2°.5, while the mean velocity is 6 miles per second. Saturn has a synodic period of 378 days, and thus comes to opposition almost every year. The period is 29.46 years.

Owing to its remoteness, Saturn appears to move very slowly among the stars. The

Ancients considered that its dull yellowish glare made it look heavy and baleful.

DIMENSIONS AND MASS. The polar compression of Saturn is greater than that of any other planet. The equatorial diameter is 75,100 miles, the polar only 67,200. The volume is 763 times that of the Earth, but the mass is only 95 times that of our own globe, indicating a very small density. Saturn has in fact only 0.7 of the density of water, and the surface gravity is only 1.17 times that on Earth. The escape velocity is 22 miles per second.

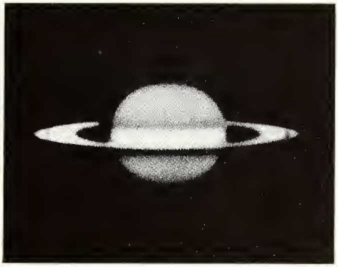
TELESCOPIC APPEARANCE. The rings of Saturn were first seen by Galileo, but not clearly enough for him to tell what they were; he believed Saturn to be a triple planet, and it was left to Huyghens, later in the 17th century, to solve the mystery. Little detail can be seen on the globe, even with large instruments; belts are visible, and occasional spots, but the rings are bound to occupy the main attention. A 3-inch telescope will show them adequately, and in a larger instrument they look superb. They lie in the plane of the equator, and twice in the $29\frac{1}{2}$-year sidereal period they are favourably presented; $7\frac{1}{2}$ years later they are seen edge-on, and owing to their thinness they then vanish except with a powerful telescope. The system presented itself fully in 1958, and the next opposition of edge-on view will be that of 1966.

CONSTITUTION OF THE GLOBE. Saturn is essentially similar to Jupiter, though its size and mass are much inferior (see **Jupiter**). On Wildt's model, the rocky core will be 28,000 miles in diameter, with an ice layer 8,000 miles deep; on Ramsey's, the core of metallic hydrogen will account for 70% of the planet's radius. The outer layer is not unlike Jupiter's, but with more methane at the expense of ammonia. The greater apparent abundance of methane is due probably to the lower temperature, −153° C. at maximum.

SURFACE FEATURES. The curved belts are not difficult objects, but lack detail. Spots are very rare. The last major outbreak occurred in 1933, when a prominent white spot was detected near the equator. It was not long-lived, but remained conspicuous for a few weeks. Spots of lesser importance have also been seen.

The equatorial zone is nearly always the brightest part of the planet, the poles being relatively dusky. Green and brown hues have been reported from time to time, but are faint and elusive.

ROTATION. The lack of well-marked features on Saturn suitable for determining the rotation period means that the values given are less accurate than in the case of Jupiter. The equatorial period is about 10 hours 14 minutes; near the poles this is longer by perhaps 20 minutes.

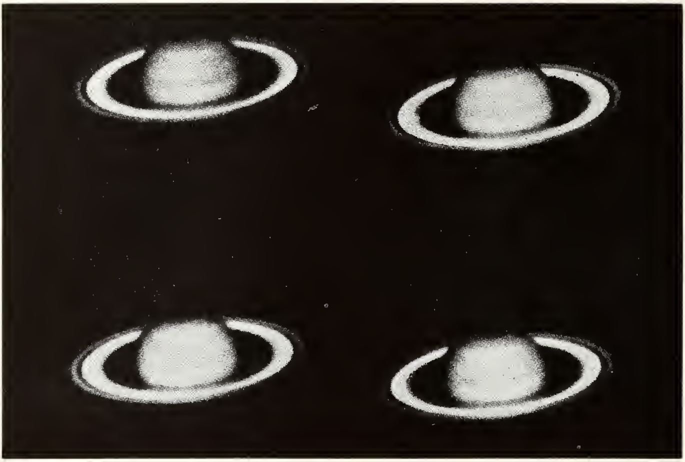


SATURN taken by the 200-inch in blue light.

THE RINGS. The ring system is of vast extent. From tip to tip it measures 169,300 miles, but the thickness is remarkably small; certainly less than 50 miles, probably no more than 10.

There are three main rings, A, B and C. Ring A, the outer, is separated from B by a well-marked gap known as Cassini's Division, discovered by G. D. Cassini in 1675. Ring B is appreciably brighter than A, while the inner ring, known as C or the Crêpe Ring, is much duskier. A dusky ring outside Ring A has been reported at various times, but has yet to be confirmed.

As early as 1857, Clerk Maxwell proved mathematically that a solid or fluid ring would be disrupted by the powerful pull of Saturn, so that the only system of rings which can exist is one composed of an indefinite number of particles, revolving round the



These beautiful photographs of Saturn were obtained by Barnard as long ago as 1911. Cassini's division in the ring system is well shown.

planet with different velocities according to their respective distances. This theory was confirmed spectroscopically by Keeler in 1895. The composition of the particles remains uncertain. It is significant that not even the two bright rings are completely opaque; in 1917 it was noticed that an occulted star remained faintly visible even when behind Ring B.

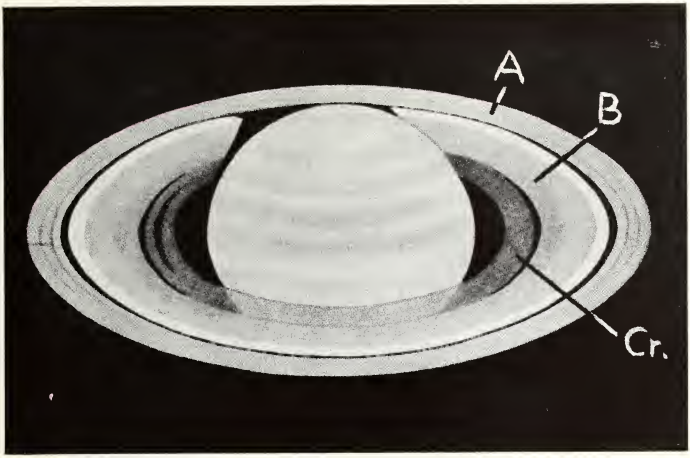
The Cassini Division is prominent enough to be seen in a small telescope when the ring system is fully presented. There is also a division (Encke's) in Ring A. Other divisions have been reported, but according to Kuiper these are mere 'ripples' and can hardly be regarded as true divisions. All these phenomena are due to the gravitational influence of Saturn's satellites, and the effect is analogous to the **Kirkwood Gaps** in the asteroid zone (see **Asteroids**).

It is curious that the Crêpe Ring, which is by no means a difficult object, should have remained undetected until the middle of the 19th century. It has been suggested that it has increased in brilliancy, but such an increase would be very difficult to explain.

SATELLITES. Saturn is attended by nine satellites. Details are given in the table under **Solar System.**

Titan has an escape velocity of over 2 miles per second. It is the largest satellite in the solar system, and is the only one known to have an atmosphere; a tenuous mantle, consisting chiefly of methane, was discovered by Kuiper in 1944. *Iapetus* is variable in brilliancy, being at its brightest when west of Saturn; clearly it has a surface which is not uniform in reflective power, and the regularity of its variations is an extra proof that it, like its companions, keeps the same hemisphere turned towards its primary (see **Tidal Friction**). *Phoebe* has retrograde motion, and alone among the satellites has a highly inclined orbit. Like the minor members of the Jovian family, it may well be a captured asteroid.

EXPEDITIONS TO SATURN. The great distance of Saturn means that no journeys there will be possible until we have progressed far beyond our present technical level. It has been suggested that Saturn's Titan will be



A drawing of Saturn, showing Rings A and B, with the Cassini Division between them, and the more transparent Crêpe Ring (Cr). The narrower divisions are difficult to observe and appear only in parts of the drawing. The tilt of the ring system remains constant as Saturn moves around the Sun, but the angle at which we see it from the Earth changes. Every fourteen years the rings appear fully opened; the next time this happens will be in 1972.

visited before any of the satellites of Jupiter, owing to the presence of a methane atmosphere, but at the moment it is pointless to speculate. (P.M.)

SCATTERING. Light which falls on a small particle is deflected and leaves in all directions; this phenomenon is called scattering. Blue light is scattered more readily than red. The particles must be of a diameter small compared with the wavelength of light – of the order of 1/100,000 of an inch.

SCHMIDT CAMERA. A reflecting **telescope** of short focal length and having a lens at the top of its tube, used to photograph the sky.

An ordinary reflector cannot photograph more than about one square degree of sky at a time; it has a parabolic mirror which gives sharp images on its own axis, but the definition falls off very seriously away from the axis.

In 1930 Bernhard Schmidt invented the optical system which bears his name. A spherical mirror is used instead of a parabolic one, and a glass correcting plate or lens of complex shape is placed at the centre of the sphere of which the mirror forms a part. The spherical mirror cannot by itself form sharp images of stars, but the correcting plate alters the paths of the light rays in just such a way as to make the mirror act like a parabaloid. A paraboloid has one, and only one, axis about which it is symmetrical, but a sphere is symmetrical about any diameter and therefore gives images of stars which are equally sharp whether they are on the axis of the telescope or not. The correcting plate permits the telescope to take photographs of areas of the sky five to ten degrees in diameter, which are wonderfully sharp right to the edge.

The focus of a Schmidt camera is not flat but curved, and the photographic plate must

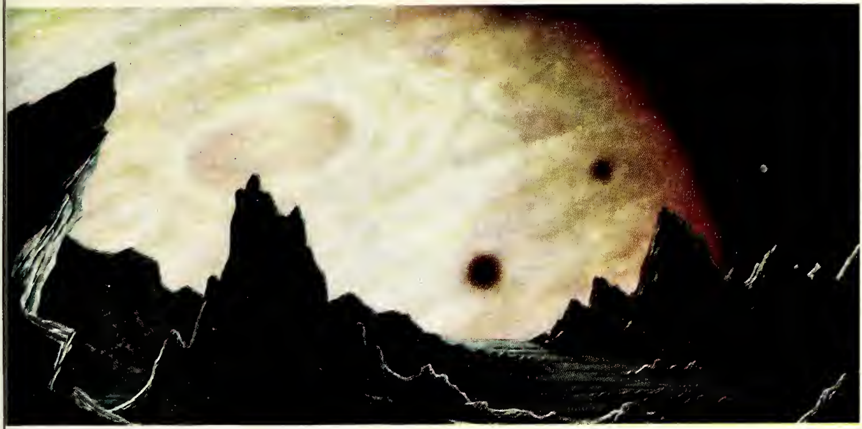
be similarly curved; sometimes specially moulded plates are used, and sometimes flat plates are bent in a special holder during the exposure. The curvature is quite small and the glass 'springs' to the required extent.

SCREENING. A wall or partition intended to protect a space or instrument from undesirable radiation. Earthed wire gauze screens against radio waves; gamma rays and **cosmic rays** can be absorbed by lead.

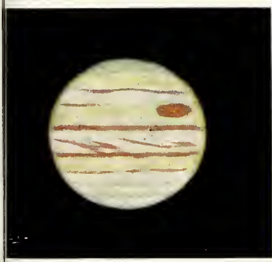
Dr. Hubble, the noted American astronomer, guiding the 48-inch Schmidt camera on Mount Palomar. Because of its wide-angle vision this instrument has been able to complete in 7 years a photographic survey of the sky which would have taken the 200-inch Hale telescope 5,000 years to accomplish.

SCINTILLATION COUNTER. An instrument which detects energetic sub-atomic particles and rays. It has a screen coated with phosphorescent zinc sulphide; a tiny flash of light signals the arrival of a particle.

SEASONS. The seasons of the year are determined by the direction of the Sun relative to the tilt of the Earth's axis, and therefore by the position of the Earth in its orbit. When the North Pole is tilted towards

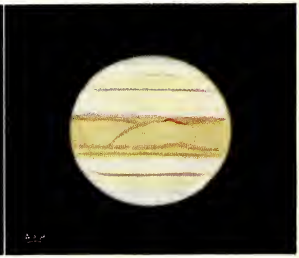


JUPITER RISING. The rapidly shifting, turbulent cloud belts of the giant planet Jupiter would form a fantastic panorama, seen from the ' grandstand ' position of its nearest satellite, *Amalthea* (also known as *Jupiter V* because it was the fifth to be discovered). Although the distance from Jupiter is usually given as around 113,000 miles, this is taken from the centre of the planet, which means that Amalthea orbits only some 70,000 miles above the cloud layers. When right above the horizon, Jupiter would cover fully a quarter of the sky, but in the scene depicted the observer is standing near the Amalthean South Pole. The *Great Red Spot* is clearly visible on the face of the planet—the picture is assumed to have been made during one of its periodical spells of prominence. The dark spots are shadows of other moons; the darkening of the limb is caused by intense atmospheric absorption.



JUPITER, 1880. The Red Spot was at its most prominent, and was described as 'strong red with a tinge of yellow'. This painting is based on a drawing made by H. C. Russell on November 3, 1880. By 1890 the Red Spot was barely visible.

JUPITER, 1914. A time of great turbulence on the surface of Jupiter. On August 29, T. E. R. Phillips observed a wealth of interesting detail — streaks and notches, as well as spots near the North temperate belt. As in all astronomical pictures, North is towards the lower edge.



JUPITER, 1959. The planet as seen by Patrick Moore with his $12\frac{1}{2}''$ reflector on March 28. The Red Spot was invisible, but the equatorial region had acquired a very strong yellow-orange coloration. This was followed by strong disturbances in the South Tropical Zone.

(Pictures by David Hardy, F.R.A.S.)

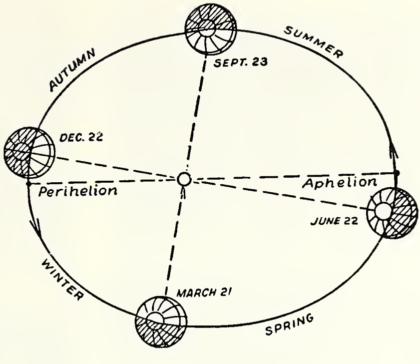
SATURN eclipsing the Sun, seen from its moon Titan. The Sun has just passed behind the eastern limb of Saturn, and it is the reddish light refracted by the atmosphere of methane and ammonia which dimly lights the icy landscape of the satellite. Two of the inner moons show opposite phases.

Titan has an atmosphere, also of methane, and that is why the sky is not black, as in the picture of Jupiter's moon Amalthea. Saturn's ring system appears edge on, and the part which lies in the planet's shadow is invisible.

(*Picture by David Hardy, F.R.A.S.*)

THE SUN AS SEEN FROM PLUTO, with its faint light reflected in frozen seas of methane. A speculative drawing by David Hardy.

Right: THE NORTHERN HEMISPHERE DURING THE SEASONS. In summer, most of the northern half of the Earth is illuminated by the Sun; in winter, most of it is in darkness, and therefore receives less heat from the Sun. Moreover, the Sun's rays strike it more obliquely during winter. Thus shorter and less effective illumination causes the winter climate to be colder. Conditions are more even in the tropics throughout the year.



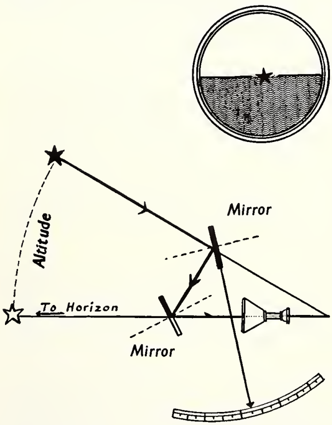
the Sun, the northern hemisphere is enjoying its summer (despite the fact that the Earth is then further from the Sun than at other times of the year). When the North Pole tilts away from the Sun, the northern hemisphere is illuminated more obliquely by the Sun, and winter sets in there while in the southern half of the globe it is summer.

SEEING. The turbulence in the Earth's atmosphere, which causes stars to 'twinkle' and makes their telescopic images unsteady.

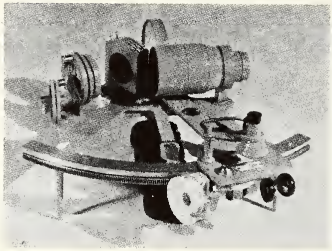
The atmosphere is never at rest, and the layers are constantly shifted by winds which vary with altitude and locally affect the density of the air. This entails irregular **refraction**, the rays of light from a star being bent this way and that. The image in a telescope often appears to jump about and 'boil'. The upper air currents may be seen by pointing the telescope at a planet with a fair-sized disc and withdrawing the eyepiece slowly: this focuses the telescope on high layers of the atmosphere and the winds at different levels can be seen streaming across the out-of-focus planetary image.

Much of the seeing, however, arises near the telescope itself through convection currents, as the instrument retains the heat of the day longer than the surrounding air. Perfect seeing is encountered only on very rare occasions, even at observatories placed high up on mountains.

SEXTANT. An instrument for the accurate measurement of the angle between the directions in which an observer sees two objects.



By moving the index arm with its mirror, light from a star can be reflected into the eyepiece of the sextant. When the star appears to be in line with the horizon, as in the circle above, the index points at the altitude of the star on the graduated rim.



A MARINE SEXTANT. The lower half of the mirror on the left is silvered, while the top half is transparent. The second mirror is half hidden by the telescope tube, and in front of it are several coloured shades for observation of the Sun etc. The graduated rim is illuminated by a small electric bulb travelling with the index arm.
(*Kelvin & Hughes*)

SHELL STAR. A star surrounded by a very voluminous, tenuous shell of gas. These shells have in many cases been thrown off by the rapid rotation of the central star. See also **Wolf-Rayet Star.**

SHOCK WAVE. A sudden change in the pressure and density of a gas, caused by the passage of some missile at a speed greater than that of sound in the gas. (See **Air Resistance.**)

SIBERIAN METEORITE. A large **meteorite** which fell in Siberia on June 30, 1908.

SIDEREAL PERIOD. The time between two successive passages of a planet or satellite through the same point on its orbit. It is also called the *period of revolution* or simple the *period.*

SIDEREAL TIME is measured by the stars and not (like civil time) by the Sun. In a sidereal day the stars appear to have made one circuit of the sky. The Sun, however, has not quite completed a circuit as the motion of the Earth in its orbit has displaced the Sun's apparent position slightly eastwards, and the Earth takes about four minutes more to 'catch up' this movement.

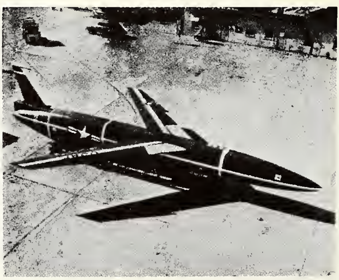
The sidereal day is hence slightly shorter than the solar day; it is $23^h\ 56^m\ 4.09^s$ of solar time. The two are in step at the autumnal equinox and sidereal time gradually gains on solar time to the extent of a whole day by the next autumnal equinox.

The *sidereal year* is the time between two successive occasions on which the Earth is in the same direction from the Sun. See **Year.**

SILICON. A chemical element whose atomic nuclei each contain 14 protons; it resembles **carbon.** It is very common in the Earth's crust and probably in the interior as well, but is not well represented in the Sun and stars.

SKY, COLOUR OF. The sky is blue. Sunlight entering our atmosphere is **scattered** by the air molecules. Blue light is scattered much more than red, so that the sunlight is reddened (instead of almost white it appears yellow) and the blue light taken from it is thrown back from molecules in all directions in the sky. As one goes higher in the atmosphere the sky becomes darker as there are fewer air molecules above to scatter the sunlight.

SNARK. A surface-to-surface winged strategic **missile** of the U.S. Air Force.



THE NORTHROP SNARK.

SOLAR APEX. The Sun, and the entire solar system with it, is moving relative to the neighbouring stars with a speed of about 12 miles per second towards a point in the constellation Hercules. This point is the *solar apex*, and the point diametrically oppo-

site to it from which the Sun is receding is the *solar antapex.*

This motion is quite distinct from that which the Sun, together with the neighbouring stars, performs about the centre of our Galaxy at a far greater speed (about 200 miles per second).

SOLAR CORPUSCLES. Particles shot off from the **Sun**, principally by flares. They are mainly **protons** and produce marked changes in the Earth's **ionosphere.**

SOLAR SYSTEM. The solar system in which we live consists of one star (the **Sun**), nine planets possessing a total of 31 discovered satellites, and a great many smaller bodies – **asteroids, comets, meteors** and those causing the **zodiacal light.**

The nine planets are described in separate articles, together with their satellites; the **Moon**, however, is discussed under its own heading. The striking characteristics of the system as a whole are given in **Solar System, Origin of.**

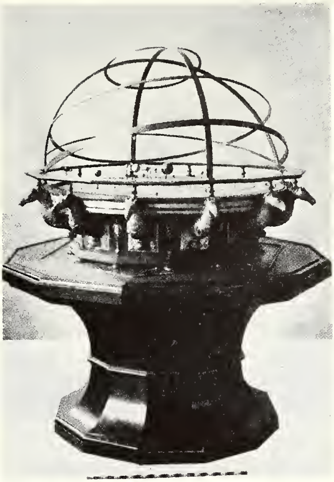
SOLAR SYSTEM, ORIGIN OF. The solar system is far from being a haphazard collectin of bodies revolving in random orbits about the Sun. A satisfactory theory of origin should at least explain the following conspicuous regularities in the system:

1. The major **planets** all have nearly circular orbits lying in approximately the same plane, and all revolve round the Sun in the same direction, which is also the direction in which the Sun rotates on its own axis.

2. All the large **satellites**, with the exception of the Moon and **Triton**, revolve in nearly circular orbits in the equatorial planes of their respective **primaries.**

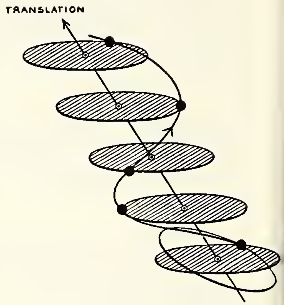
3. The distances of all except the two outermost major planets from the Sun are represented by **Bode's Law.**

4. The major planets fall into two groups. Mercury, Venus; the Earth and Mars are relatively small and dense, and have few satellites and long rotation periods; Jupiter, Saturn, Uranus and Neptune are relatively large and have low densities, many satellites and short rotation periods. About Pluto little is yet known.

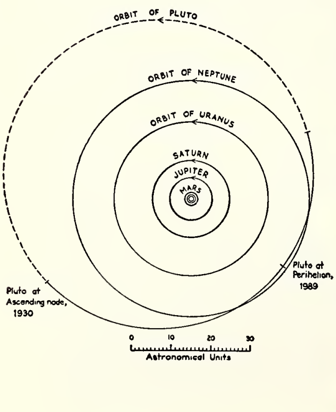


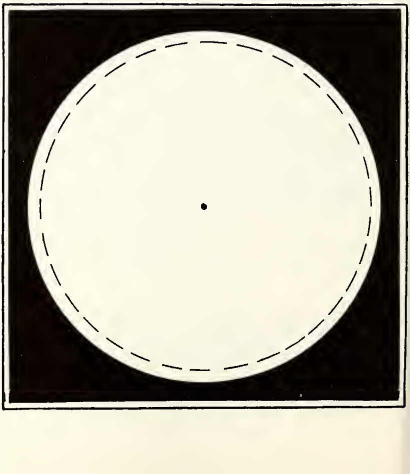
A LARGE ORRERY or clockwork model of the solar system, made in 1733. The spheres representing the planets travel in grooves about the Sun at the centre, being raised and lowered by their supporting rods according to the inclinations of their orbits. The brass rings represent the ecliptic (resting on the horses' heads), the celestial equator, the Tropic of Cancer and the Arctic Circle; the two vertical hoops cross at the celestial North Pole. The orrery can keep time with the motions of the planets, and shows their configurations at a glance. (*Science Museum*)

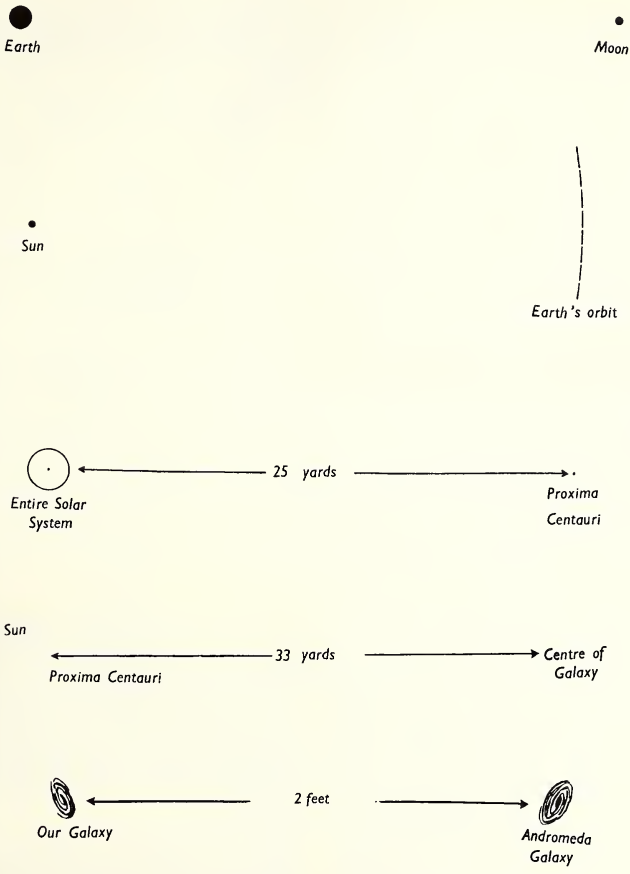
Two basic types of theory of the origin of the solar system have been proposed: one seeks to show that the system could have arisen from a nebula, or a cloud of dust and gas, while the other invokes some catastrophic event, such as the close passage of another star causing the Sun to eject matter, or the



THE SCALE OF THE SOLAR SYSTEM. At top left, the large white disc is the Sun, with Jupiter, Saturn, the Earth and the Moon in its orbit round the Earth drawn to the same scale. At top right, the curved line joining the small black circles shows the Earth's motion round the Sun while the latter, together with the entire solar system, moves in the direction of the arrow. At right bottom, a medium-sized red giant star is drawn to scale with the Sun (central dot) and the Earth's orbit within it.







THE SCALE OF THE ASTRONOMICAL UNIVERSE. From top to bottom: (1) Earth, Moon and the distance between them drawn to the same scale; (2) the size of the Sun compared with the radius of the Earth's orbit; (3) the Sun at the centre of the solar system, and its nearest neighbour; (4) and (5) are self-explanatory. A diagram showing the distribution of clusters of galaxies is given in the article on Cosmology.

TABLE OF PLANETS

PLANET:	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Diameter (*miles*)	3,100	7,700	7,900	4,200	88,000	71,000	32,000	31,000	8,000?
Mass (*Earth = 1*)	.04	.82	1.00	.11	1318	736	64	39	1.0?
Density (*Water = 1*)	3.8	4.9	5.5	4.0	1.3	0.7	1.3	1.6	5?
Surface velocity (*Earth = 1*)	.27	.86	1.00	.37	2.64	1.17	0.92	1.44	1?
Escape velocity (*miles/sec*)	2.2	6.3	7.0	3.1	37	22	13	14	7?
Rotation period	88d	?	23h 56m	1d 0h 37m	9h 55m	10h 38m	10h 40m	15h 50m	6d 9h
Solar distance, mean (*million miles*)	36	67	93	142	484	887	1,790	2,800	3,680
Sidereal period	88 days	225 days	365 days	687 days	11.9 years	29.5 years	84.0 years	164.8 years	248.4 years
Eccentricity	.206	.007	.017	.093	.048	.056	.047	.009	.249
Inclination to Ecliptic	7.0°	3.4°	0°	1.9°	1.3°	2.5°	0.8°	1.8°	17.3°
Synodic period (*days*)	116	584		780	399	378	370	367	367
Incl. of equator to orbit	0°	32°	23.5°	25.2°	3.1°	26.7°	98.0°	29°	7°?
No. of Satellites	0	0	1	2	12	9	5	2	?

spontaneous disruption of the Sun itself. All theories of the latter class are open to the fundamental objection that the material ejected from a star would be at enormous temperature and pressure, and on being released into space it would certainly explode and could not possibly condense to form planets.

The theories involving a nebula, which could conceivably have been acquired by the Sun from interstellar material, assume the nebula to have been in slow rotation about the Sun; collisions between its component particles would cause it to become disc-shaped. The earliest theory was that of Kant, who supposed that the matter in the disc would collect in local aggregations and ultimately form planets. Another early theory, by Laplace, suggested that the nebula gradually contracted, and in doing so speeded up its rotation to conserve **angular momentum** until successive rings of matter, later to form the planets, were thrown from the equator. On the basis of the theories of Kant and Laplace, the Sun is expected to possess most of the angular momentum of the solar system. The theories are untenable because the planets, possessing little more than a thousandth of the total mass, have 98 per cent of the angular momentum and the Sun only 2 per cent.

The most satisfactory theory so far, initially put forward by von Weizsacker, involves the formation of vortices in the nebular disc. Plausible reasons are given for expecting the vortices to occur in rings, with five vortices in each ring. Between successive rings secondary eddies, rather like roller-bearings, develop gradually. Favourable conditions for condensation and accretion of

TABLE OF SATELLITES

Planet	*Satellite*	*Mean distance from primary (million mi.)*	*Period (days)*	*Diameter (miles)*	*Stellar magn. (max.)*
Earth	Moon	.24	27.32	2,160	—12.5
Mars	Phobos	.0057	.32	10	11
	Deimos	.0146	1.26	5	12
Jupiter	V	.11	.50	100?	13
	I Io	.26	1.77	2,320	5.3
	II Europa	.42	3.55	1.950	5.7
	III Ganymede	.67	7.15	3,200	4.9
	IV Callisto	1.17	16.69	3,220	6.1
	VI	7.1	251	70?	15
	X	7.2	254	10?	19
	VII	7.3	260	30?	17
	XII	13.0	620	15?	19
	XI	14.0	692	15?	18
	VII	14.6	739	15?	17
	IX	14.7	745	15?	18
Saturn	Mimas	.12	.94	300?	12.1
	Enceladus	.15	1.37	300?	11.7
	Tethys	.18	1.89	700?	10.6
	Dione	.23	2.74	700?	10.7
	Rhea	.33	4.52	1,000	10.0
	Titan	.76	15.95	3,500	8.3
	Hyperion	.92	21.28	200?	15
	Iapetus	2.21	79.33	800?	10.8
	Phoebe	8.05	550.45	200?	14
Uranus	Miranda	.077	1.41	80?	17
	Ariel	.119	2.52	300?	16
	Umbriel	.166	4.14	250?	16
	Titania	.282	8.71	600?	14
	Oberon	.364	13.46	600?	14
Neptune	Triton	.220	5.87	2,800	13
	Nereid	3.46	359.4	130?	20

planetary material exist in these roller-bearings; it is however difficult to find a mechanism for the ultimate coalescence of the ten eddies in each ring to yield the planets. Detailed mathematical analysis shows that the theory can give a law such as Bode's relating the radii of the planetary orbits to each other, and can probably also explain the differences between the inner and outer planets; the angular momentum difficulty too can be overcome. Thus, although no theory is completely satisfactory yet, there is hope that further work on Weizsacker's may yield an acceptable solution to the problem. (R.G.)

FOUR PLANETS. The first three have been photographed with the Mount Wilson 100-inch, Pluto with the Palomar 200-inch telescopes. The bands on Jupiter and Saturn are well-marked.

SOLSTICE. One of the two occasions during the year when the Sun, in its passage round the **ecliptic**, reaches a maximum distance from the celestial equator, i.e. when its declination is at its greatest. This happens about June 22, the *summer solstice* for the northern hemisphere, and about December 22, the *winter solstice*. At the summer solstice daylight lasts for a longer, and at the winter solstice a shorter, time than at any other period of the year.

SONDE. A rocket or balloon carrying instruments to probe conditions in the upper atmosphere. (See also **Planetary Probes.**)

SOVEREIGNTY IN SPACE. It has often been supposed in a Utopian sort of way that, by the time space flight became a reality, world politics would have risen above the need to assert national rights in space. In the event, political and strategic considerations have provided the greatest single incentive to the development of rockets and space research, and the difficult question of sovereignty in space is now receiving serious attention. It need not be approached in the spirit of the 19th-century pronouncement that 'the Moon is an entirely German object', but the very absence of any doctrine of law relating to space can only encourage such claims in the future.

One proposal from the Institute of International Air Law at McGill University is that the air above a country up to the heights where ordinary aircraft can operate be called territorial space; that this region be extended upwards to 300 miles as contiguous space in which there is freedom of transit for all non-

military vehicles while ascending or descending; and that no territorial rights be extended beyond this limit.

As the Earth rotates, it is meaningless to think of parts of outer space lying 'above' a particular country; moreover, artificial satellites can hardly avoid being over a large number of countries within a few hours. At the same time, every State will have to be responsible for the conduct of its rockets and satellites as it is for that of ships under its flag on the high seas, otherwise confusion may result. National rights on the Moon are being discussed as well, but no doubt even there possession will prove to be nine points of the law.

SPACE MEDICINE. The new field of medical science which studies the human factors involved in space flight, and which provides for the first time a link between medicine and those branches of science which deal with matters of an extraterrestrial nature. As the method of propulsion on which space flight is based is the rocket, space medicine is essentially the physiology of rocket flight.

Medical problems in space flight stem, in the first place, from the environment of space *per se* and from the process of movement through this environment. Of special interest to us are the altitudes at which the characteristics of space flight begin, and what protective measures must be taken; one of the most important is the climatization of the cabin. Other problems encountered are the state of weightlessness, high accelerations during launching and during re-entry into the atmosphere, visual problems, and the lack of day and night. It is too early, however, to discuss all these problems. We shall, therefore, confine out medical considerations to

(1) effective height of the atmosphere,

(2) the climitazation of the space cabin, and

(3) the state of weightlessness.

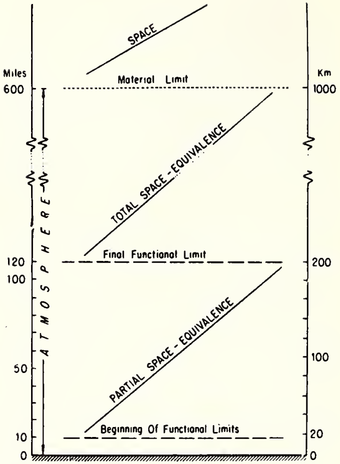
EFFECTIVE HEIGHT OF THE ATMOSPHERE. At an altitude of 600 miles the atmosphere ceases to be a continuous medium because collisions of the air particles become very rare. This is the physical border between the atmosphere and space. The various functions of the atmosphere for manned flight, however, come to an end at much lower altitudes, some even within the stratosphere. These altitudes are called the functional limits of the atmosphere.

The functions of the atmosphere can be divided into three principal categories: life-sustaining pressure functions, life-protecting filter functions, and flight-supporting aerodynamic functions. In the following, we shall subdivide these further, and shall use ten of the most important functions as a basis for the differentiating between atmosphere flight and space flight:

(1) The atmosphere supplies us with oxygen for respiration; in space there is no oxygen. This atmospheric function comes to an end at 50,000 feet. At first glance this seems strange, because the atmosphere contains free oxygen at much greater heights than this. The reason is that the air in our lungs is constantly maintained at a rather high pressure by carbon dioxide and water vapour, both issuing from the body itself. The pressure of carbon dioxide is 40 mm. of mercury, of water vapour 47 – a total of 87 mm. of mercury. The air pressure of 87 mm. corresponds to an altitude of about 50,000 feet. Above this altitude no air can enter the lungs, for the pressure is greater inside than out; the contribution of the atmosphere to respiration is zero, just as if we were surrounded by no oxygen at all, as in space. This is the first of the most important functional limits of the atmosphere, or *space equivalent levels* within the atmosphere.

(2) The atmosphere exerts upon us sufficient barometric pressure to keep our body fluids from boiling. The water vapour pressure of our body fluids is about 47 mm. of mercury; as soon as the pressure falls below this our body fluids will 'boil'. Such a pressure is found at 63,000 feet. This is the second functional border of the atmosphere or space equivalent level within the atmosphere.

(3) In the denser zones of the atmosphere the outside air is compressed to pressurize the cabin; in space, there is no outside air to be compressed. In space we need a new type of cabin which is pressurized from within, a sealed cabin in which a climatically adequate atmosphere for the occupants must be arti-



At about 11 miles the atmosphere already fails to provide the oxygen and the external pressure needed for survival, and special equipment has to be worn. Then, one by one its other protective functions cease until at 120 miles it might as well not be there at all from the medical point of view, although traces of it extend up to 600 miles.

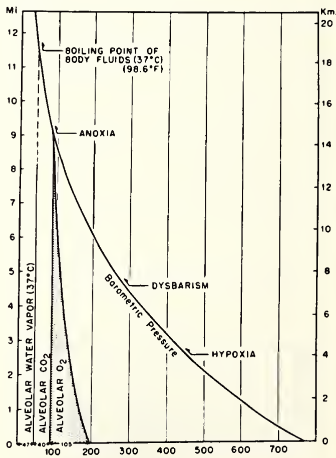
ficially maintained. Such a space cabin is required even down to 80,000 feet, for above this height there is too little air available for compression. Therefore, with regard to the necessity of a sealed cabin, space begins at 80,000 feet.

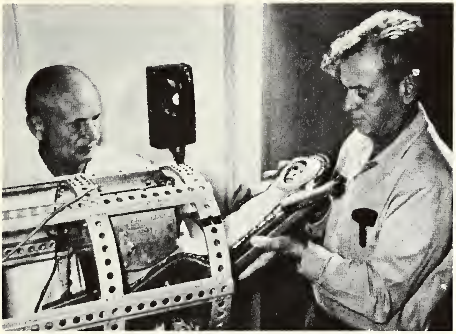
(4) In the lower altitudes we are protected from **cosmic rays** by the atmosphere's filter function – in space no such natural protection exists. Below 120,000 feet, the rays lose their original power in collisions with the molecules of the air. Above 120,000 feet, however, we are beyond the protecting shield of the atmosphere, as in space.

(5) In the lower layers of the atmosphere we are protected from the sunburn-producing **ultra-violet** of solar radiation. In space, there is no protecting medium. It is the ozone layer between 70,000 and 140,000 feet altitude that forms a kind of umbrella against ultra-violet by absorbing the larger portion of these rays. Beyond 140,000 feet ultra-violet is effective in its full range as in space.

(6) In the denser layers of the atmosphere light is scattered by the air molecules producing the blue daylight, against which the stars fade into invisibility; in space the stars are visible against a dark background at all times to the dark-adapted eye. The transition zone from atmospheric optics to space optics lies at a height of about 80 miles.

DANGERS OF FALLING AIR PRESSURE. At a height of 2½ miles, the blood no longer carries the normal amount of oxygen. At 4–5 miles, mountain sickness or *dysbarism* sets in: breathing becomes laboured and interrupted, the slightest exertion feels like hard work, and curious mental symptoms begin to show, such as partial loss of memory, extreme stubbornness, dullness and lethargy. At 9 miles, the pressure of the oxygen in the air is lower than in the lungs, and none of the still plentiful oxygen can be absorbed by the body. Pressurized flying suits with breathing equipment can overcome all these difficulties.





SPACE COUCH for a monkey being inserted into a biopack container before launching in a *Mercury Project* test. The couch holds the body in a position similar to that shown in the diagram on p. 158. The monkey has already been accustomed to the biopack in ground tests.

(7) From ground level we sometimes see **meteors**, which are vaporized by friction with the air while still at an altitude of 50 to 70 miles. Above this level we are beyond the meteor-safe wall of the atmosphere, as in space.

(8) The lower atmosphere transmits sound waves; at higher altitudes sound propagation becomes impossible, as the air molecules do not collide often enough to transmit the disturbances. The region where this occurs lies between 50 and 100 miles.

(9) The atmosphere provides aerodynamic support or lift for a moving craft; space cannot. The dynamic support from the air ceases at 120 miles, for any speed. This then is the aerodynamical border between atmosphere and space.

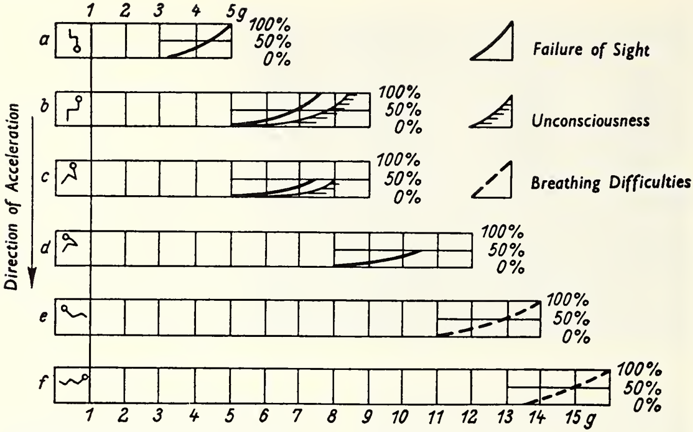
(10) The atmosphere contains and transmits heat energy; in space, heat is transmitted by radiation exclusively. In the lower and middle altitudes friction with the air molecules causes high temperatures at the surface of a fast-flying vehicle. Above 120 miles this cannot occur, owing to the low density of the air.

This consideration, based upon ten atmospheric functions, reveals that the larger portion of the atmosphere is equivalent to free space. The region in which we encounter some, but not all, factors typical of space must be considered as partially space equivalent. This begins at 50,000 feet. The region above 120 miles is distinguished by total space equivalence when we ignore some variations caused by the bulk of the Earth itself, its magnetic field, its speed, and its own and reflected radiation. The 120-mile level is, therefore, the final functional limit of the atmosphere.

CLIMATIZATION OF THE SPACE CABIN. This is one of the most important space-medical problems. As already mentioned, the cabin must be a completely closed compartment and it is required even as low as 80,000 feet. This means that the problems of space flight lie immediately on our doorstep.

Under the conditions of space flight a man may consume in respiration about $1\frac{1}{2}$ lbs. of oxygen per day. This must be replaced in such a way that the pressure of oxygen does not fall below 100 mm. of mercury, since this is about the minimum permissible limit for efficiency; nor exceed 350 mm., because concentrations above this level are toxic. The oxygen used in respiration is converted into carbon dioxide, which is poisonous in concentrations above 3%. To be on the safe side, it is advisable to keep its concentration below 1% by removing the excess chemically.

There is a natural process in our atmosphere which produces oxygen and consumes carbon dioxide. This is the photosynthesis of green plants. It may be possible to utilize this



THE EFFECTS OF ACCELERATION FOR VARIOUS BODY POSTURES. Postures are indicated on the left. The percentages apply to the number of subjects tested, not to the degree of the disturbance. (*H. von Diringshofen*)

process for cabin climatization; it has been found that 5 lbs. of a certain green alga can meet the respiratory requirements of one man.

The climatization of the cabin designed for space operations must also include temperature, humidity, and odour control.

Finally, the barometric pressure must be kept at a suitable level. It need not be more than $\frac{2}{3}$ of that at sea level on the Earth, and in this respect the physiologist could make concessions to the engineer, who for structural reasons would desire the lowest satisfactory pressure.

The multitude of factors involved in the climatization of the sealed cabin requires a complex of instrumentation for automatic control, and experiments are being made with sealed chambers in which the changes of atmospheric conditions caused by the presence of the occupants, and the means to control these factors, can be studied.

WEIGHTLESSNESS. There is one environmental factor that can hardly be substituted in a space craft – the normal gravitational force of the Earth, the force responsible for our weight. In space flight the vehicle and the crew will be weightless, a condition which will bring home the difference between the mass and weight of a material body. Mass is an intrinsic property of matter, weight depends upon external forces.

Weightlessness is perhaps the most revolutionary feature in the coming development of flight. It is also the problem which causes the most confusion, expressed in the question: where and when do we leave the gravitational field of the Earth? The answer is – nowhere and never. Weightlessness is, however, produced when the gravitational force of the Earth is allowed free play, and can act equally on a vehicle and its crew. This condition is known as **free fall**.

From this point of view of space medicine, there are two main questions to be answered:

(1) What is the effect of weightlessness upon the pilot's sense of orientation in space and upon his ability to control the craft?

(2) How does weightlessness affect the general well-being?

We have several gravity-sensitive organs, or specific nerve endings that serve as *gravireceptors*, such as the otolith organ of the ear, and the receptors of the pressure sense over the entire skin (about 20 per square centimetre). These receptors have an *exteroceptive* function insofar as they react to external forces such as gravity and inform us about the outside world; a *proprioceptive* function insofar as they inform us about the tension conditions in the skin, the muscles, and the connective tissues. They play, therefore, an important role in the control of the movements of the body.

In the gravity-free state the exteroceptive or gravireceptive function of the receptors is eliminated; the proprioceptive function, however, is not. For this reason, a man making a dive from a high diving-board is able to perform a variety of acrobatic stunts quite skilfully, although he is in a state of free fall throughout the dive. In this gravity-free state the absent gravireceptive function of the receptors must be substituted by the exteroceptive sensory organs *par excellence*: the eyes. In free fall, the eyes will be the only sense organs that inform their owner of his position in space.

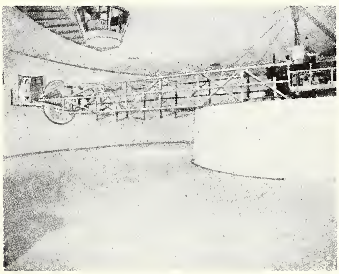
Experiments have recently been carried out to study the effect of weightlessness on human beings. The subjects had to perform certain aiming tests during the state of weightlessness. Most men learned very quickly how to cope with this situation.

Some of the gravireceptors, namely the otolith organ and those found in the abdomen, have strong reflex connections with the nervous system, which controls circulation, digestion, etc. During abnormal motion conditions, as on a ship during rough weather, these conditions manifest themselves in the form of nausea and sickness. The opinion has frequently been expressed that we might expect similar disturbances in space flight. However, during the gravity-free state such abnormal excitations do not occur; instead, the gravireceptors, after a short transition period, reach a new equilibrium.

The whole problem is reduced to the question of the possibility of adapting to the state of zero gravity. This adaptation seems possible.

The question of tolerance of weightlessness is an important problem for the engineer. If the crew cannot tolerate weightlessness, then the engineer must provide for artificial gravitation, which of course poses additional technical difficulties.

The centrifuge (*below*) which at the end of its rotating arm carries the gondola (*above*). The equipment is used to test human reactions to centrifugal force equivalent to accelerations of over 10g. Physiological sensing devices, television cameras and X-ray and film cameras help to study the subject while the gondola is in motion. (*Ministry of Supply*)



TRAINING OF ASTRONAUTS. A large number of experiments with rocket-borne animals such as the dog carried in *Sputnik 2*, and the monkeys in nose-cones which were later recovered, have shown that the mammalian organism can survive and remain in good health in space, given adequate protection.

The results also emphasized the value of intensive training in promoting physiological and psychological adaptation to the stresses of space flight.

The following tests, to which all **Mercury** astronauts have been subjected, are a typical part of such training:

Altitude Tests: the subject is placed in an altitude chamber dressed in a pressure suit and taken 'up' gradually or by explosive decompression. His reactions, heart rate, blood pressure, etc., are measured and he is in telephonic communication with the outside. He must remain capable of obeying instructions and of manipulating controls.

Gravity Tests: the subject is submitted to high accelerations in the gondola of a centrifuge, and to short periods of **free fall** in aircraft.

Heat Tests: subjects are submitted to short periods of intense heat and to prolonged periods of moderate heat with simulated partial failure of the refrigerated suits.

Equilibrium Test: the subject is placed in a chair which rotates simultaneously on two axes, and must keep the chair on an even keel by handling controls, normally and blindfolded, with or without vibration.

Cold Pressor Test: parts of the body are plunged into ice water, while changes in the blood circulation are observed.

Sensory Impoverishment Tests: curious disturbances can arise if a mammal is deprived of all external stimulation for long intervals. Subjects are placed on a very soft, moulded cushion in a dark, soundproof, odourless cabin with smooth, featureless walls, and must remain in this state for many hours without experiencing hallucinations or other mental or physical symptoms.

These are only some of the problems involved in space flight, centred mainly around the climatization of the space cabin and the state of weightlessness. Nevertheless, we can make the cautious statement that all the medical problems involved in space flight seem to be surmountable; the human factor is probably not an absolutely limiting factor – it is a modifying factor in this grand project of our century. (H.S.)

SPACE MIRROR. A large mirror in a satellite orbit, capable of focusing sunlight upon the Earth. Unfounded rumours that such a mirror or 'Sun-gun' was planned by the Germans to turn upon cities circulated at the end of the Second World War. In fact a mirror very many miles in diameter would be needed to have any appreciable effect.

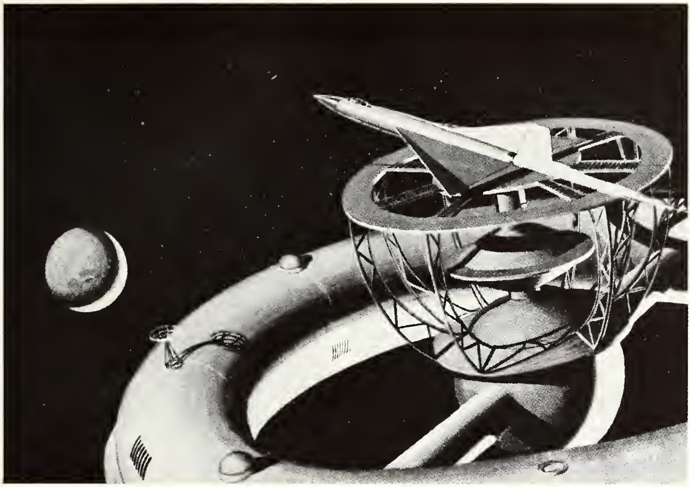
SPACE SHIP. A manned rocket for interplanetary voyages. Such vessels are now practicable on a very limited scale for journeys within the solar system. With great advances in rocket propulsion, the neighbourhood of the nearest stars such as the Centauri system may one day become accessible, but more extended travels over ranges of tens of light-years or even between galaxies, and the use of hyperdrive and space-warps belong exclusively and permanently to science fiction.

SPACE STATION. A manned artificial satellite built in orbit from materials ferried up by rockets.

In contrast to unmanned artificial satellites and to rockets which leave the Earth and ultimately return to it after a limited stay in a satellite orbit, space stations *as defined above* can serve no purpose that is not better served in other ways. This becomes clear from the following considerations:

1. The construction of a space station from components already placed in an orbit by a fleet of ferry rockets is ludicrously uneconomic. There is no point in building such a station unless it is substantially bigger than any that could be sent up complete as spaceships, and it would therefore require many ferry rockets for its supplies; and any one of these ferries could be used as a manned space ship, orbiting the Earth for a period of a few weeks or months and performing all the duties that a space station could carry out.

2. The military value of a space station is nil: if one country can build an elaborate manned station, another can certainly provide a small guided missile to destroy it, and a tremendous amount of money and labour which could



A SPACE STATION and the Moon, illuminated by the Sun from the right and by reflected light from the Earth on the left. Such stations will probably never be needed. (*Picture Post*)

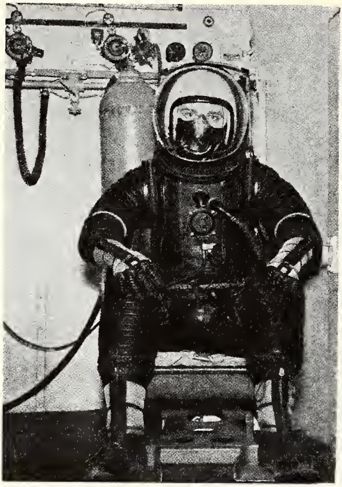
have been more profitably spent on direct forms of armament would, in an instant, be brought to nought. For offensive purposes, intercontinental missiles have every advantage; as an observation post, a space station can do no more than a manned rocket – probably very little in either case.

3. For a fraction of the cost involved in a space station's construction and maintenance a very large number of radio relay stations could be built and serviced on the ground in various parts of the globe; there is no scope for a space station in this field.

4. Meteorological observations are again more economically made by automatic weather satellites such as **Tiros** or by manned rockets temporarily placed into orbits. The value of such observations is problematical.

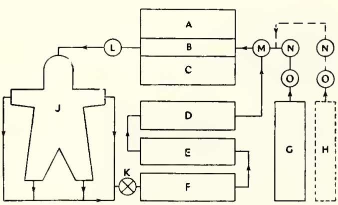
5. One of the chief arguments for space stations has always been the fact that they could serve as **orbital refuelling** bases. But by the time it is possible to build such stations it will no longer be necessary to take on fresh supplies of propellents in order to start interplanetary journeys, and it can only be concluded that space stations will be obsolete before they are practicable.

6. It will be no more difficult to erect an astronomical and physical observatory on the Moon than in space, and the Moon provides a far more desirable and permanent platform than any artificial satellite. If a large station can be built piecemeal under free fall conditions in orbit, a rocket for the return journey can be assembled and supplied on the Moon.



A U.S. AIR FORCE PRESSURISED SUIT which enables the wearer to survive space-equivalent conditions near the limit of the Earth's atmosphere.

THE T-1 HIGH ALTITUDE SUIT protects flyers against explosive decompression should the airplane cabin pressure fail in the near-vacuum of the upper atmosphere. The suit inflates itself automatically. (*U.S. Air Force*)



Block diagram of a protective suit similar to the one above: –
A – cooling unit; B – temperature control unit; C – heating unit; D – unused-gas cleanser; E – carbon dioxide remover; F – excess water remover; G – oxygen storage cylinders; H – helium storage cylinder; J – survival suit; K – gas circulating pump; L – high-pressure relief valve; M – recycled gas injector valve; N – manual 'flow and stop' valve; O – pressure reducing valve.

SPACE SUIT. A space suit's construction depends to some extent upon where it is to be used, i.e. on the Moon, in **free fall**, etc., but certain functions are essential.

1. The suit must be pressurized to prevent boiling of the body fluids. If it is flexible it would tend to become rigid like an inflated tyre; the pressure would spread-eagle the 'inhabitant'. Considerable ingenuity is being expended upon this problem, as a rigid suit with articulated joints is less desirable than a flexible one.

2. Oxygen must be provided for respiration, and the exhaled gases purified or disposed of: this entails at least an oxygen cylinder being included in the suit. In a state of weightlessness the cylinder could be quite large, but on a planet with a reasonable gravitational field weight would be an important consideration, and the oxygen supply more limited.

3. Some form of temperature control is essential. If the occupant of the suit is in

shadow he will need heating, presumably by electricity from batteries, or alternatively insulating, in which case regulation of heat losses must be provided to prevent him overheating. For use in sunlight, the suit would probably require in addition a refrigerating system. A present space suit might therefore be justifiably described as a portable, air-conditioned, person-shaped room.

SPECIFIC HEAT of a substance is the number of **calories** required to raise the temperature of one gram of it through 1° C. Specific heats vary considerably, e.g. that of water = 1, and that of lead = 0.03. This means that the same amount of heat which will raise the temperature of water by 1° C. will raise an equal weight of lead through about 33° C. Thus bodies of low specific heat may be at very high temperatures and yet contain relatively little heat.

SPECIFIC IMPULSE. A measure of the effectiveness of a rocket engine, defined as its thrust (in pounds) per pound of fuel and oxidant consumed per second. This is equal to the **exhaust velocity** divided by g.

SPECTRAL CLASSIFICATION OF STARS. Most of our knowledge of stars is derived from analyses of their spectra. There are so many stars, even in our own Galaxy, that to study them all individually would be a quite hopeless task. A classification had therefore been adopted: stars of similar spectra are placed in the same spectral class, and only typical members of the class need then be investigated in detail.

The classes of spectra grade into one another, so that they can be arranged in a continuous sequence. In order of the spectral sequence, the classes are rather unsystematically named

O, B, A, F, G, K, M.

Each class is divided into subclasses numbered 0 to 9; thus the Sun is class G2; Algol, B8.

The science of **spectroscopy** has shown the sequence to be essentially a *temperature sequence*, with O stars at the hot end and M stars relatively cool. The luminosities of stars vary in a recognizable way according to their spectra: this is the basis of the **Hertzsprung-Russell Diagram.**

The spectrum of a normal star consists of a bright background crossed by dark lines, and these lines determine the spectral class. There is a smooth and progressive change along the sequence, a line at a particular wavelength appearing at a certain point, rising to a maximum intensity, and fading away through the succeeding classes. An astronomer classifies a spectrum simply by looking at the lines and comparing them by eye with a series of standards, some of which are reproduced below.

The chief characteristics of the spectral types are as follows:

O: essential feature is presence of lines of ionized helium.

B: neutral helium, strong hydrogen lines. No ionized helium.

A: hydrogen lines dominate the spectrum. Maximum at A0, later decrease as many lines due to metals appear; ionized calcium conspicuous among these.

F: hydrogen lines continue to weaken. Prominent lines of ionized calcium, the so-called H and K lines.

G: hydrogen lines weaker, metals stronger, surpassing hydrogen in later G spectra. First traces of molecules. H and K lines strong.

K: H and K lines declining. Strong metallic lines.

M: many molecular bands, especially those of titanium oxide. Very strong line of neutral calcium.

There are a few other classes of spectra which have received letter designations. Certain very hot stars, the **Wolf-Rayet stars**, have been placed in a class W allied to the type O. Classes R, N and S are similar in temperature to the M stars but seem to differ chemically: instead of titanium oxide the R and N stars contain much carbon, while S stars contain the exotic element zirconium.

A few stars do not fit in any of these classes. They are termed 'peculiar' in contrast to the 'normal' stars belonging to the recognized types. Among peculiar stars may be mentioned:

i. **White dwarfs**, which show very broad hydrogen lines and scarcely anything else.

ii. **Shell stars** – O, B and A stars surrounded by a tenuous shell of gas which superimposes emission lines on their spectra.

iii. Many **variable stars**.

iv. All **novae** have very peculiar spectra, with bright forbidden lines and other curious features.

v. Certain stars show greater intensities of certain spectral lines than normal stars of similar temperature. The chief group is that of the peculiar A stars. (R.H.G.)

SPECTROSCOPY is the science relating the nature of luminous sources to the characteristics of the light they give out.

How can we know what substances exist in a star, how can we discover its temperature, pressure and size, how indeed can we know anything about an object we see only as a speck of light, separated from us by an almost unimaginable void? The key to these problems is spectroscopy, the detailed and unremitting analysis which exacts the last iota of all the evidence contained in a star's light.

Spectroscopy began in 1666, when Newton made his classic discovery that white light is made up of many colours. A narrow beam of sunlight was allowed to fall on a triangular glass **prism**. The beam emerged from the prism as a band of colours. This band is called a *spectrum*.

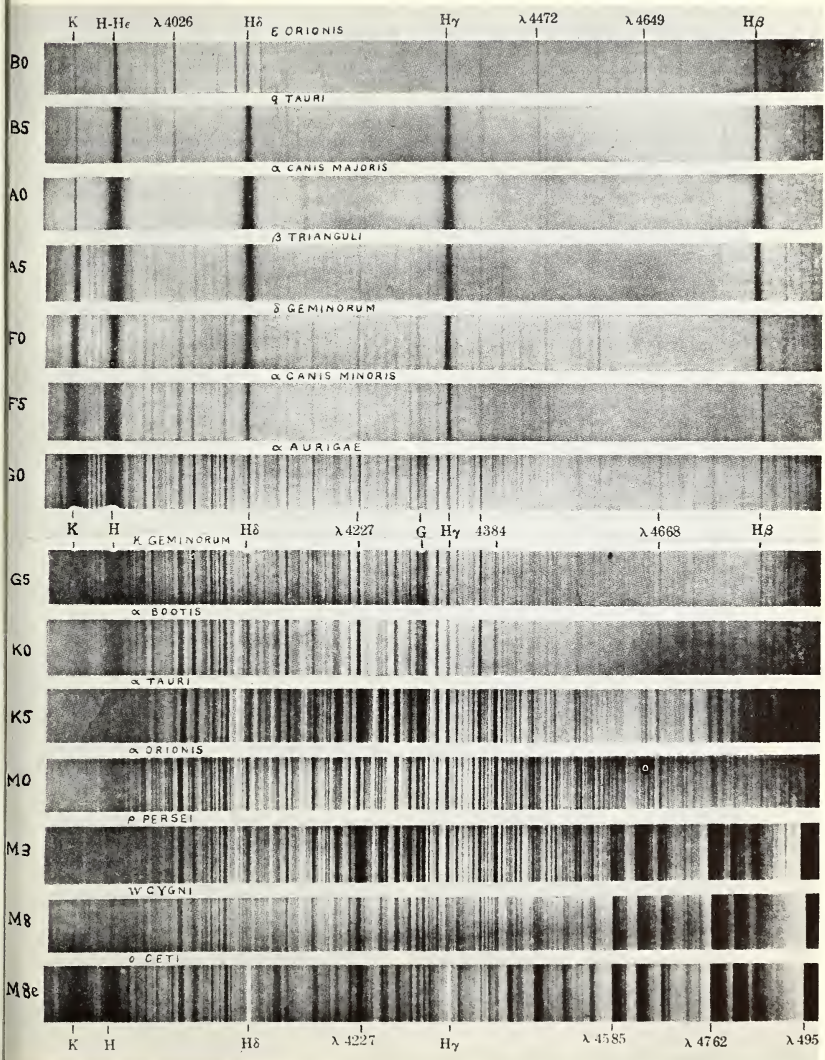
Newton showed that the colours did not originate in the glass but were contained in the original beam of light. Later it was noticed that the spectrum was crossed by a number of narrow dark lines, some darker and broader than others. In 1817 Fraunhofer examined the spectrum of a lamp, and saw how different it was from the solar spectrum. Later he found that the Moon and planets had spectra similar to that of the Sun. Fraunhofer saw over 750 lines in the solar spectrum and mapped out over 300. He ascribed letters to the principal lines, and some of these letters are still used by astronomers. He examined the spectra of several of the brighter stars. Some (Capella, Procyon, and others) has spectra crossed by dark lines in exactly the same positions as the lines in the solar spectrum. Others (Sirius and Castor) showed only a few very intense black lines which had no very obvious connection with solar spectrum lines.

The true interpretation of these observations was found by two German chemists, Kirchhoff and Bunsen, in 1859. They realized that some of the dark lines seen in the solar spectrum had the same positions as certain bright lines in the spectra of laboratory sources. When light from a bright source was passed through a flame containing sodium, a pair of dark lines appeared in the yellow region of the spectrum of the source. Removal of the flame caused the lines to disappear. The lines were obviously due to absorption by sodium in the flame.

The colour plate facing p. 257 illustrates diagrammatically the dispersion of a beam of white light into a spectrum by a prism; the absorption of a part of this spectrum in the yellow region by a sodium flame; and the resulting absorption spectrum. The wavelengths absorbed by the flame are the same as those which it emits in all directions; virtually none of this scattered yellow light reaches the screen or photographic plate on which the spectrum appears, and the missing wavelengths give rise to the absorption lines. The correspondence of absorption and emission lines characteristic of a particular substance or element is illustrated by the lower part of the diagram: if the sodium flame is used as the original source of light, the prism does not produce a continuous spectrum because most wavelengths are not contained in the light from the source. It produces instead an emission spectrum of yellow lines on a dark ground, the reverse of the absorption spectrum.

The use of other substances instead of sodium produced different sets of lines. Kirchhoff and Bunsen showed that these sets of lines, characteristic of particular elements, could be used to identify these elements in the

Opposite: THE CLASSIFICATION OF STELLAR SPECTRA. The spectral type appears on the left margin; the name of the type star above its own spectrum. Some noteworthy lines, especially of hydrogen (H) and potassium (K) are also marked. Numbers refer to wavelengths in Angstrom units. The temperatures of the stars decrease down the table; only the coolest stars display the characteristic fluted bands of molecular spectra.


K
H-Hε
λ 4026
Hδ
Hγ
λ 4472
λ 4649
Hβ
B0
ε ORIONIS
B5
η TAURI
A0
α CANIS MAJORIS
A5
β TRIANGULI
F0
δ GEMINORUM
F5
α CANIS MINORIS
G0
α AURIGAE
K
H
Hδ
λ 4227
G
Hγ
4384
λ 4668
Hβ
G5
κ GEMINORUM
K0
α BOOTIS
K5
α TAURI
M0
α ORIONIS
M3
ρ PERSEI
M8
W CYGNI
M8e
o CETI
K
H
Hδ
λ 4227
Hγ
λ 4585
λ 4762
λ 495

sources of spectra. By taking a substance and exciting its spectrum by causing its vapour to glow, the chemical composition of the substance could be obtained. This was the beginning of *spectrochemistry*, the science of chemical analysis by spectroscopic methods. Kirchhoff enunciated his famous law, that the ratio of the absorbing power of a substance to its emitting power for light of a particular wavelength is the same for all substances at a given temperature. Kirchhoff soon saw that the Sun must be surrounded by layers of cool gases absorbing light emitted by the hotter layers below, the absorption lines being characteristic of the atoms present in these outer layers of the Sun. Thus a method had been discovered which permitted the study of the chemical composition of the Sun and the stars. This can be said to be the beginning of modern *astrophysics*.

COLOUR AND WAVELENGTH. Light is a form of **electromagnetic radiation**, and consists of waves. The distance from the crest of one wave to that of the next is called the *wavelength*; it is so small that it is convenient to measure it in **Angstrom Units** (abbreviated A).

Visible light has wavelengths between 4,000 A and 7,000 A. When light of one particular wavelength falls on the eye a sensation of colour is produced. Different colours correspond to different wavelengths. Light of wavelength 4,000 A is violet in colour, and as the wavelength increases the colour changes continuously through blue, green, yellow, orange and red until, for a wavelength of 7,000 A, a very deep red sensation is produced. For longer wavelengths still, no sensation of colour is produced, but the radiation can be recorded on photographic plates up to 14,000 A; such radiation is called infra-red. Radiation below 4,000 A is called ultra-violet, and is easily recorded photographically.

Most astronomical work is concerned with the range from 3,000 A to 10,000 A. Outside this range the Earth's atmosphere absorbs all the ultra-violet and much of the infra-red, preventing such radiation reaching us from celestial objects. Recent experiments with rockets have, however, enabled the ultra-violet spectrum of the Sun to be obtained.

TYPES OF SPECTRA. It is possible to have emission spectra and absorption spectra, each of which can exist as continuous, line and band spectra.

Emission spectra are seen when light from a hot source is examined directly by a spectroscope. *Absorption* spectra are formed when a source giving a continuous emission spectrum is viewed through absorbing material; gaps are seen in the emission spectrum in places corresponding to the absorbed wavelengths.

A *continuous* spectrum is one which shows an uninterrupted band of wavelengths. A *line* spectrum consists of a number of relatively sharp emission (or absorption) lines separated by spaces where there is no emission (or absorption); and a *band* spectrum consists of a very large number of closely spaced lines, often overlapping to a considerable extent.

Hot glowing solids and liquids produce continuous emission spectra. Hot gases may produce continuous emission spectra if the gases are sufficiently opaque, because of their high density or because they occupy a very large volume. Gases at lower densities or in smaller amounts give line or band spectra in emission. Cool layers of gas in front of a hotter source of continuous emission produce a line, band or continuous absorption spectrum.

INSTRUMENTS. The *spectroscope* is the instrument which enables the astronomer to examine spectra by eye. For most purposes it is however more convenient to obtain a photographic record, and when the instrument incorporates a camera it is called a *spectrograph*.

A *diffraction grating* is often used instead of a prism in a spectroscope. It consists of a very large number of closely-spaced parallel grooves ruled with a diamond on either a polished glass surface (*transmission grating*) or on a metallic mirror (*reflection grating*). There may be over 15,000 grooves to the inch. When light falls on a grating the different constituent colours emerge at different angles and form a spectrum which can be made sharper and better drawn out than one formed by a prism.

MEASUREMENTS. In order to measure the wavelengths of lines on a spectrum and to identify them, some standard of comparison is needed. This is obtained by photographing

the known spectrum of some laboratory source side by side with the unknown spectrum.

DOPPLER EFFECT. The whole spectrum of a celestial body is often noticeably displaced relative to the comparison spectrum. This displacement is caused by the **Doppler effect** and is a measure of the **radial velocity** of the body.

It is important to remember that the observations of the Doppler effect give the velocity of the object relative to the observer on the moving Earth. It is usual to correct measurements for the orbital motion of the Earth; radial velocities of stars and nebulae are given *relative to the Sun.*

ATOMIC SPECTRA. Every **atom** has its own characteristic pattern of spectral lines or bands. For many atoms these patterns are complicated; despite this, almost all the observed lines can be explained.

HYDROGEN SPECTRUM. The simplest spectrum is that of hydrogen. The hydrogen spectrum shows a series of obviously related lines extending from the red to the ultraviolet and converging to a well-defined limit. This series is observed in the spectra of stars like Sirius; more lines are seen in the stars than in laboratory spectra.

In 1885 Balmer found a simple mathematical law which predicted the correct wavelengths for the hydrogen lines. The hydrogen series has been named the Balmer Series in his honour.

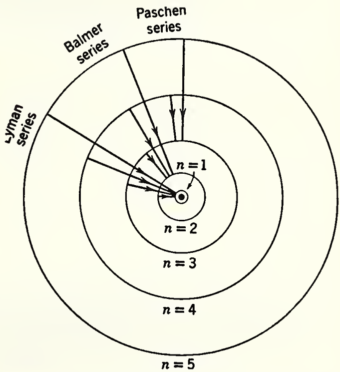
Other similar series of lines have been observed in the hydrogen spectrum: the Lyman Series occurs in the far ultra-violet around 1,000 A, and the Paschen Series and Brackett Series lie in the infra-red region of the spectrum.

The mathematical law discovered by Balmer predicts correctly the positions of *all* the lines in *all* the series. Such a law could not arise by accident, and must be related to the internal structure of the hydrogen atom. It is interpreted in terms of atomic structure by a theory now of fundamental importance to many branches of physics, the *quantum theory.* This theory postulates that energy is radiated and absorbed only in whole multiples of a certain very small unit, the *quantum.*

THE HYDROGEN ATOM. We may think of the hydrogen atom as consisting of a nucleus of one **proton**, with one **electron** in an orbit around it.

The electron can move in any one of a number of circular orbits of fixed sizes. In any particular orbit, the electron has a certain energy; this energy is greater for larger orbits. As there are only certain possible sizes of orbit there are also only certain possible amounts of energy or *energy levels.*

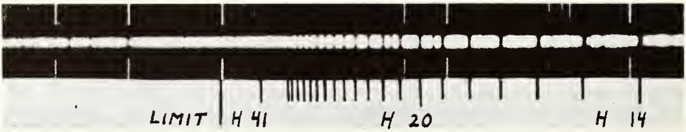
The electron can change its orbit, but can only do so by a 'jump': it cannot, for instance, spiral from one orbit to another because a spiral is not a possible orbit.



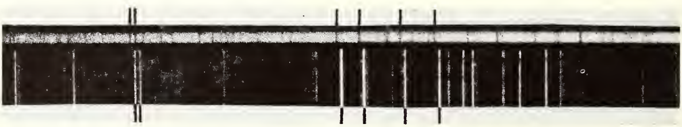
Whenever an electron jumps from a higher into the lowest (innermost) orbit, the atom gives out radiation at a wavelength corresponding to a spectral line of the Lyman series. Jumps down into the second lowest level contribute to the Balmer series (*see opposite*). The greater the jump, the closer the emitted radiation is to the limit of the series, which is reached when an electron enters from outside the atom.

Every time the electron jumps between orbits it must give out or take up energy, for as well as changing its orbit it is correspondingly jumping from one energy level to another. A jump or *transition* between any pair of levels involves a definite energy change, the difference between the energies of the two levels.

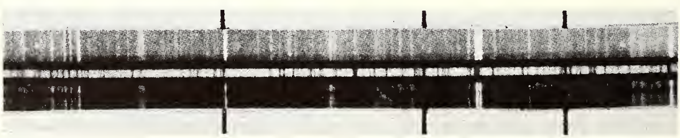
LINE EMISSION SPECTRUM of an iron arc.



THE BALMER SERIES of hydrogen in the spectrum of the shell star HD 193182. The lines are distinguished by the quantum number of the upper energy level of the corresponding electron jump. The lines from H14 to H 33 are marked, and on the original plate lines up to H 41 can be seen. The position of the Balmer limit is also shown. Above and below the star spectrum are iron compariscn spectra.



THE DOPPLER EFFECT in the spectrum of the star Zeta Herculis. Six iron lines are marked in the star and the comparison spectrum. (*R. H. Garstang*)



PART OF STAR SPECTRUM of spectral type K 5 between two iron comparison spectra. The stellar spectrum shows dark absorption lines against a continuous emission background. Two prominent calcium lines are marked in the right half. (*R. H. Garstang*)

This change is manifested by the emission or absorption of one quantum of radiation. The energy change in the transition determines the size of the quantum, which in turn determines the wavelength of the radiation.

Radiation is only emitted or absorbed when the electron jumps from one orbital state to another: an electron in one of its orbits does not radiate or absorb energy while remaining in the same state, and can only change its state by absorbing or emitting radiation of just the correct wavelength.

Thus every spectral line represents a transition between particular energy levels within the atom.

Even in the largest possible orbit the electron has only a certain energy. If it acquires more than this critical amount, it is no longer bound to the nucleus. It is found that the electron can possess *any* energy above this amount, and not just certain particular energies. The process of removal of electrons from an atom is called ionization.

If ionized atoms and free electrons intermingle in a volume of space, the electrons must frequently collide with the ionized atoms, and it is possible for the electron to jump into one of the empty orbits of the atom, emitting its surplus energy as radiation. This process is termed *recombination*. Because the free electrons have a continuous range of energies, the radiation given out in a recombination process has a continuous spectrum.

ATOMS AND SPECTRA OF OTHER ELEMENTS. The ideas given above can be applied to other elements than hydrogen, but complications arise owing to the multiplicity of electrons in all such elements.

All atoms, however, can be regarded as having a number of fixed energy levels, and each spectral line is the result of a transition between particular levels.

In atoms with more than one electron, multiple ionization is possible: an atom may lose several of its electrons under suitable conditions. In the solar corona atoms of iron exist that have lost fourteen of their electrons, and at the high temperatures in the centre of the Sun iron atoms lose on an average twenty-four out of their twenty-six electrons.

The removal of an electron entirely alters the electrical field inside an atom; consequently the possible orbits for the remaining electrons change, and the ion has quite a different spectrum from the parent atom.

FORBIDDEN LINES. These are spectral lines of certain elements, which, while theoretically possible, i.e. corresponding to the difference of energy between two states, are not observed in laboratory spectra, although they have been found in the spectra of various astronomical sources. Their importance lies in the information they yield about the nature of the sources. Under laboratory conditions atoms undergo frequent collisions with other atoms, ions and electrons. Collisions can excite atoms from one state to a higher state, and can de-excite them to a lower state, without any spectral line being absorbed or emitted. Forbidden lines occur only in emission. The atoms concerned must be dropping from higher to lower states by emission of radiation.

In the case of a normal or 'permitted' line, the excited atom radiates and so falls to a lower energy level in about one hundred-millionth of a second. The weakness of forbidden lines is explained by assuming that an atom spends anything from a second to an hour before emitting them. If atoms are in a level from which downward, permitted lines are possible, such lines will be strong. If no such lines are possible, forbidden lines will be emitted if the atoms have the requisite time to do this. Collisions must be infrequent, and this will be the case only if the pressure and density are low enough. This is true in the outer parts of the atmospheres of the Earth and Sun, in the gaseous nebulae and in interstellar space. From the intensities of forbidden lines we can estimate the temperatures and densities of these sources.

THE 21 CM. WAVE. Many spectral lines, originally thought to be single, have been found to consist of groups of lines exceedingly close to each other. This has been attributed to a spin of the atomic nucleus; for most atoms it may be ignored, but there is one outstanding exception. The smallest orbit or *ground state* of hydrogen is a single energy level on the usual quantum theory. When account is taken of the spin of the nucleus the ground state is seen really to be a *doublet* – a pair of energy levels extremely close together. The difference between the levels corres-

ponds to a wavelength of 21 centimetres. This wavelength is in the radio region of the **electromagnetic spectrum**, and has been detected from interstellar hydrogen in the Galaxy (see **Radio Astronomy**).

MOLECULAR SPECTRA differ greatly from atomic spectra, because molecules can possess energy due to vibration between the constituent atoms, due to rotation and to many other factors which cannot apply to separate atoms. A typical molecular spectrum contains patterns of bands or *flutings* instead of a number of sharp lines.

BREADTH OF SPECTRUM LINES. If atoms and molecules behaved exactly as we have described, absorption and emission lines would be of one precise wavelength only. Examination of almost any spectrum shows that whilst some absorption lines are narrow and dark, others are broad and diffuse. There are many factors which contribute to the breadth of a spectrum line.

(a) *Natural breadth.* The simple picture of an atom assumes that each energy level corresponds to one and only one precise energy. This idea has been modified in the light of detailed treatments of the problem, and each energy level is now thought of as spreading over a narrow range of energies. A transition between any two levels therefore has a small but distinct range of energies, and the corresponding spectral line has a small but distinct spread. This natural breadth is a property of the atom, and does not depend on its surroundings.

(b) *Collisional broadening.* If an atom which is in the process of radiating collides with another atom, the train of light waves emitted by the atom is interrupted; the interruption has the effect of widening the spectral line. Collision broadening is clearly of most importance in dense sources where collisions are frequent.

(c) *Doppler broadening.* The **Doppler effect** applies to all moving sources of radiation. The individual atoms in a gas are moving rapidly in random directions, and these motions give rise to shifts in wavelength on either side of the mean wavelength for the gas as a whole. The effect is again to broaden the spectral lines. The broadening depends upon the velocities of the atoms and increases with temperature, so that it is greatest in hot stars.

(d) *Turbulence.* In many stellar atmospheres large scale motions take place. Lines from the various moving clouds of gas suffer additional Doppler shifts, and the nett effect on the spectrum is to broaden the lines still further.

(e) *Stark broadening.* The countless ions in a star's atmosphere cause strong electrical fields between the atoms. These slightly disturb the electrical fields *inside* the atoms, in which the electrons move. The changes cause slight differences in wavelength between lines emitted by different atoms, and the overall effect is to broaden the spectral lines.

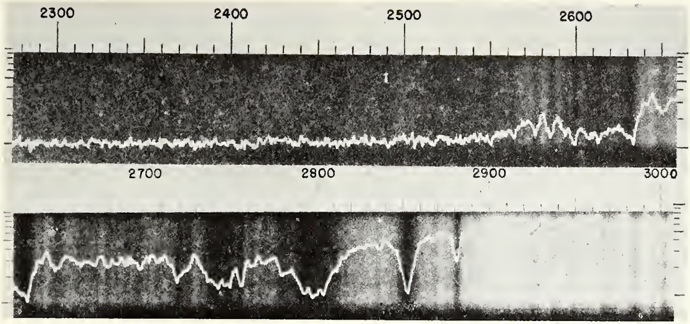
(f) **Zeeman effect.**

(g) *Rotation.* Many stars are in rapid rotation. Different parts of the surface of a star may have different velocities towards or away from the observer owing to rotation of the star: light from these parts therefore shows Doppler shifts corresponding to all these velocities. The spectrograph necessarily photographs the spectra of both **limbs** simultaneously, as the star appears just as a point source of light; the lines are consequently broadened by the rotation of the star.

(h) *Instrumental broadening.* All the broadening factors so far listed arise in the star itself. But various factors combine to make even the most perfect astronomical instrument produce some blurring effect.

The observed breadths of spectral lines are caused by a combination of some or all of the above factors. One of the principal problems of astronomical spectroscopy is to distinguish as many of the above effects as possible in a given spectrum.

SPECTROSCOPY IN ASTROPHYSICS. When a large number of lines in a stellar spectrum have been identified and their strengths measured, it is possible to study the temperature and pressure and chemical composition of the outer layers of a star.



The ultraviolet spectrum of the Sun, photographed at an altitude of 50 miles from a V–2 in 1947. The wavy line is a graph of the brightness of the spectrum.

The degree of ionization of the atoms of an element depends on the temperature and pressure. Electrons are removed from an atom by collision with another atom or ion, or by absorption of radiation; both the number and violence of the collisions, and the amount of radiation, are increased by increasing the temperature, and the number of collisions is increased by raising the pressure. On the other hand, increase of temperature or pressure entails more frequent collisions between ions and electrons, and therefore more frequent opportunities of recombination; this process reduces the degree of ionization. An equilibrium is set up, in which the number of electrons removed from atoms by collision or radiation is just balanced by the recombination of ions and electrons. The results of detailed investigation on the influence of pressure and temperature on ionization are embodied in an important quantitative law, known as *Saha's Equation*, after its inventor.

Translated into terms of spectra, this means that at low temperatures an element shows the lines of its neutral atoms, and with rising temperature the lines of the singly ionized atoms become progressively stronger at the expense of those of the neutral atoms, only to be themselves superseded by the spectrum of the doubly ionized atoms. Different elements ionize with different ease: thus, while ionized calcium is already important at 3,000° C., helium scarcely begins to ionize until 10,000° C. is reached.

Thus we are able to explain the observed sequence of stellar spectra as a temperature sequence, the classes from O to M being classes of decreasing temperature.

The relation between temperature and the colour predominant in the light emitted from a hot source is beautifully exemplified in the colour photograph of the Owl Nebula facing p. 257. This shell of gas fluoresces under irradiation by invisible ultraviolet light from the very hot blue star at its centre. The temperature of the glowing gas decreases outwards from the central star, and the colour varies accordingly from blue in the middle to red at the outer fringe.

The effect of pressure is slight, but it affords us a useful way of distinguishing between diffuse *giant stars* and relatively dense *dwarf stars*. We have already seen that higher pressure leads to lower ionization: it follows that a dwarf star shows rather lower ionization than a giant of the same temperature. Different elements respond to changes in pressure to different extents, and the relative strengths of nearby spectral lines of elements of differing pressure sensitivities are measured to give an indication of the size of a star.

STELLAR ATMOSPHERES. The light which we receive from a star comes from near the surface, as the material of stars is quite opaque – this is evident from the apparent sharpness of the Sun's limb. The absorption lines seen in the star's spectrum are caused by the removal of certain wavelengths from the original light after it starts its journey to us, and therefore an investigation of the absorption lines can only enable us to decide what absorbing atoms exist *above* the opaque part of the star – in short, in the star's atmosphere. To discover the abundance of an element in the atmosphere of a star, the intensities of the spectral lines due to that element must be measured.

The results of the analysis of stellar atmospheres are surprising: nearly all stars have very similar atmospheres, and the differences between the classes of stellar spectra, so great at first sight, are caused almost wholly by differences of temperature and pressure.

It is found that hydrogen and helium, in the ratio of about five to one, preponderate vastly over all other elements. The following typical figures for the commonest of the other elements show that, at least as far as the atmospheres of stars are concerned, they may all be considered as trace elements:

Element	*Percentage*
Oxygen	0.068
Neon	0.064
Nitrogen	0.020
Carbon	0.013
Iron	0.008
Magnesium	0.004

(R.H.G.)

SPECTRUM. See **Spectroscopy**.

SPEED OF LIGHT. The fact that light does not travel infinitely fast, and arrive at its destination instantaneously, was first deduced in the 17th century. Occultations, and other phenomena, of Jupiter's satellites were found to occur systematically earlier than predicted at some times of the year, and later at others: this could be explained on the assumption that light took an appreciable time – about 15 minutes – to cross the Earth's orbit. A number of ingenious systems have been devised to determine the very short time that light takes to traverse a measured path, either either inside a laboratory or outside (sometimes between mountain tops many miles apart). The most recent and accurate measurements yield a value of 299,793 kilometres per second (about 186,000 miles per second).

SPHERICAL ABERRATION is a defect of mirrors and lenses with spherical surfaces, light from the inner and outer parts of the lens or mirror converging to slightly different foci and so preventing the formation of a sharp image. It is reduced by altering the shapes of the surfaces concerned.

SPIRAL NEBULAE, SPIRAL GALAXIES. See **Extragalactic Nebulae.**

SPUTNIK. The name given to Russian artificial Earth satellites.

STANDARD TIME. A system of time measurement used by most countries in the world. It would make life very difficult if every place on the Earth kept strictly to its local mean time based on the position of the Mean Sun. Under the standard or *zone time* system, the same time is adopted throughout the area between two lines of longitude 15° apart; the local time varies one hour across the zone. The time in each zone differs from that in the adjacent zones by one hour.

STAR. A glowing sphere of gas. Unlike the planets, the stars shine by their own light: they are indeed burning fiery furnaces, where matter is pent up at inconceivable pressures and heated to inconceivable temperatures. They are not, however, 'burning' in the ordinary sense – **stellar energy** is produced, not by chemical but by *nuclear* reactions similar to that of the hydrogen bomb.

The nearest star to the Earth is the **Sun,** which is quite a typical example. Many stars are bigger and brighter than the Sun, yet so vast is the space between us and them that they appear as mere glittering specks in the night sky, their rays overpowered by the light of day.

Every star is a gigantic globe containing enough matter to make something like a million Earths – and even our puny Earth 'weighs' 6,000,000,000,000,000,000,000 tons! Most of this stupendous amount of material we cannot see; it is hidden deep below the

star's surface. **Spectroscopy** gives us a surprisingly detailed insight into the surface conditions, and from these we can deduce a little about the stellar interiors. Stars are found to be formed largely of hydrogen, which seems to be the essential element in the make-up of our Universe.

Despite the tremendous size and mass of a star, our own local star system, the Galaxy, contains some 100,000 million of them; and even a galaxy pales into insignificance on the cosmic scale, the Universe certainly containing many thousands of millions of them.

The physical characteristics of stars – their temperatures, sizes, masses, etc. – and the methods used to determine these are described below. It is apparent that a great deal of our knowledge is based upon observations of **binary stars.** Details of star temperatures, diameters, masses, densities and surface gravities are given in the article on the **Hertzsprung-Russell Diagram.**

TEMPERATURE. A number of possible ways of measuring temperature may be enumerated:

1. From the spectral class.
2. Kinetic Temperature, from the Doppler broadening of spectral lines (see **Spectroscopy**). The velocities of the random motions of atoms are proportional to the square root of the absolute temperature. This method of estimating temperature is not readily applicable to absorption spectra, but the random velocities can be found from line-widths in some emission spectra of objects such as gaseous nebulae and the solar corona.
3. Effective Temperature, from the total radiation of the star (**Bolometric Magnitude**) and apparent diameter, using **Stefan's Law.** Methods of measuring star diameters are described in the next section.
4. Colour Temperature, found from Colour Index, described under **Magnitude**. This is a useful method.

RADIUS. Stellar radii are all too small to measure directly through a telescope, but other methods are available:

1. Eclipsing binary stars: this is the most important method.
2. The Stellar **Interferometer.**
3. The method of estimating the Effective Temperature, given in the last section, may be used in reverse to supply the apparent diameters of stars, using assumed effective temperatures based on alternative methods of temperature estimation.

The radii of stars are found to differ prodigiously. The smallest turn out to be about the size of the Earth; they belong to the class known as *white dwarfs.* On the other hand, some stars are so gigantic that they would extend to the orbit of Saturn if placed with their centres in the position of our Sun. The larger component of the eclipsing binary star system ε Aurigae must be about two thousand million miles in diameter.

MASS. The masses of stars can only be satisfactorily determined from observations of binary stars. A few stars are known to show a red shift in their spectral lines which is caused by the formation of the lines in a strong gravitational field. The Theory of Relativity predicts such a shift to be proportional to the mass and inversely proportional to the radius of the star. To find the mass we must therefore first find the radius, as well as disentangle the observed slight red shift from the ordinary Doppler effect. The uncertainties of this method are so great as to render the results of doubtful value.

The masses of stars vary far less than the radii; most masses are about that of the Sun, and few lie outside the range 0.15 to 15 Sun's masses as far as we know. It is an observational fact that the mass of a star is very closely related to its luminosity, but this must be regarded only as a relationship for stars on the Main Sequence of the Hertzsprung-Russell Diagram and near the Sun; it is not necessarily true of all stars everywhere.

DENSITY. This follows directly from the mass and radius.

SURFACE GRAVITY. This is an important quantity in the investigation of stellar atmospheres. It, too, is obtained from mass and radius.

ROTATION. The rates of rotation of a few eclipsing binary stars are measurable directly; otherwise they may sometimes be deduced from a study of the shapes of absorption lines. see **Spectroscopy**.

MESSIER 16, a galactic nebula of intermingling hot and cooler gases in violent motion. The small, compact, dark *Globules of Bok* are believed to be stars in an early stage of formation. The larger globules may give rise to an entire star cluster, such as the Pleiades. Their final condensation into stars may be very sudden, each globule collapsing violently under the pull of its own gravitational field.

(*Mount Wilson – Palomar*)

LUMINOSITY. This is a very important quantity, and is stated in terms of the absolute **magnitude** of the star. The faintest known star is of absolute magnitude 19; the brightest stars, and the ordinary novae, are around −8, and the brightest supernovae about −17. The Sun's absolute magnitude is 4.7. A relationship between mass and luminosity for stars near the Sun has been given. The period-luminosity law for Cepheid and RR Lyrae variable stars is described in **Stars, Distances and Motions.**

THE HERTZSPRUNG-RUSSELL DIAGRAM. We have seen that it is possible to discover many of the things we should like to know about the stars, albeit only approximately and for only certain of them. As at least some of the important characteristics of many stars are known, it is natural for us to ask if we can see any system in the make-up of stars, and if they conform to any general plan. The answer to such questions is that general relationships do seem to hold between the characteristics of most stars. The gradation of spectral classes and the mass-luminosity relationship have already been noted; but perhaps the most informative pattern which can be seen in the make-up of stars is that shown by the **Hertzsprung-Russell Diagram**.

STAR GLOBE. A sphere having the positions of stars marked on its surface; it is a model of the celestial sphere. It would only show the stars as they appear in the sky if viewed from the *inside* of the globe; from outside we see the mirror-image of their relative positions.

STARS, DISTANCES AND MOTIONS. The motions of stars relative to ourselves are measured in two directions: observations of **proper motion** show movements perpendicular to the line of sight, and those of **radial velocity** reveal motions in the line of sight. One conclusion from these measurements is that the Sun itself has a proper motion relative to nearby stars (see **Solar Apex**).

Remote stars may have their distances determined if their apparent and absolute magnitudes are known. The Cepheid and RR Lyrae **variable stars** are extremely valuable, and have been called the 'yardsticks of the Universe'. Their mean luminosities are very closely related to their periods of variation. While the relationship was correctly determined in the first place, absolute magnitudes of all Cepheids and RR Lyrae stars have until recently been in doubt, and may still be slightly in error, as none of these stars has a measurable parallax. A re-determination of the magnitudes of RR Lyrae stars in 1952 resulted in our ideas of the size of the Universe being roughly doubled. It is fortunate that Cepheids are so bright that they can be recognized in the nearest extragalactic nebulae. RR Lyrae stars are too faint to see or photograph in any extragalactic systems other than the Magellanic Clouds. (See also **Parallax** and **Distances, Astronomical.)**

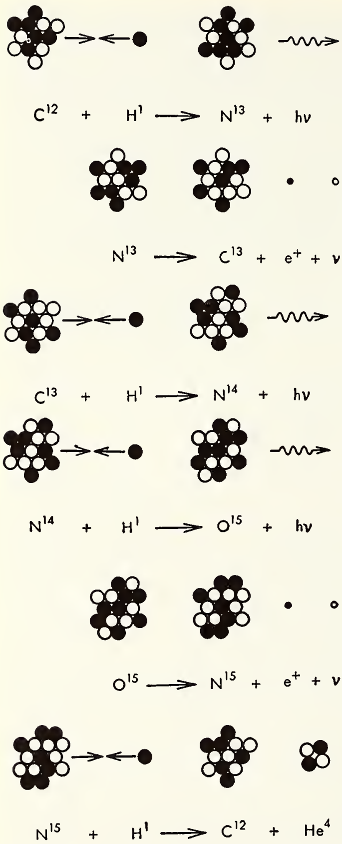
STATIC FIRING. A test of a rocket motor conducted on a stand on the ground instead of in a rocket in flight.

STEFAN'S LAW. The law describing the radiation of heat from a **black body**. The heat radiated per square inch of the body's surface is proportional to the fourth power of the **absolute temperature**.

STELLAR ENERGY AND INTERIORS. The Sun, despite its relatively unimpressive absolute magnitude of 4.7, radiates as much energy every second as would be released by the explosion of several billion atomic bombs. The only conceivable sources of such a stupendous quantity of energy are nuclear reactions.

The temperatures of stellar interiors may be estimated from the physical conditions at the surface and a knowledge of the laws of physics. It is concluded that the centres of main sequence stars, at least, are all at fairly similar temperatures, of the order of 15,000,000° C. As analysis of star atmospheres suggests that the Universe is endowed with, to say the least, a goodly proportion of hydrogen, it is natural that we should look for a nuclear reaction which consumes hydrogen and goes at a reasonable rate at fifteen million degrees Centigrade. It turns out that there are two such plausible reactions.

The first is the *carbon-nitrogen cycle.* In this, four successive hydrogen nuclei combine with a carbon nucleus, energy being liberated at each state. The carbon is transmuted into nitrogen during the first three additions, but the fourth addition regenerates the original



THE CARBON-NITROGEN CYCLE. It begins with a collision between a proton and a carbon atom containing 12 protons (C 12), yielding nitrogen 13 and a gamma ray. The nitrogen decays spontaneously into carbon 13, a positive electron and a neutrino. A series of further reactions ultimately reforms carbon 12, together with an alpha particle; meanwhile, there have been three releases of energy.

carbon nucleus and gives also a helium nucleus. Helium is stable at stellar temperatures. It is worth noting that further carbon cannot be formed at these temperatures. The carbon-nitrogen cycle is thought to be the principal source of energy of the stars in the earlier spectral classes.

The second reaction is the *proton-proton reaction*. A proton is the nucleus of a hydrogen atom; such a nucleus combines successively with three more to give a helium nucleus with the liberation of energy. This reaction is more likely to occur in the stars of later spectral type.

Thus the nett effect of both reactions is to transmute four hydrogen nuclei into one helium nucleus. When this occurs about half of one per cent of the mass of the hydrogen disappears, being converted into energy.

The Theory of Relativity shows that the rate at which hydrogen must be used up to account for the observed energy release of stars like the Sun is such that these stars could continue to radiate at their present intensities for a period several times as great as their probable ages (about 5,000 million years). On the other hand, very luminous giant stars would exhaust their hydrogen in comparatively few million years, suggesting that they must be very young on the cosmic time scale.

There are other possible reactions besides the two mentioned above. They involve the light elements lithium, beryllium and boron, and take place at lower temperatures than the carbon-nitrogen and proton-proton reactions. All three of these light elements are present in stars only as minute traces: they may have been used up already in nuclear reactions.

Our picture to-day of what goes on inside a star is coloured largely by our ideas about **convection**. It seems likely that, throughout much of the bulk of a star, convection cannot take place and all energy must be transmitted by radiation alone; also the helium formed by transmutation from hydrogen cannot be mixed with the rest of the matter of the star but must remain where it is produced. Convection however does take place in the outermost layers of the star – in the Sun the tops of the convective cells can be seen, giving rise to a granular appearance on the surface. The generation of energy in the star is confined to a small convective core in which mixing can take place. It appears that, when the

hydrogen of the core is all used up, energy generation takes place in a shell round this convective core, as no hydrogen can reach it from the non-convective region outside.

It is conceivable that the catastrophic explosions of supernovae may be due to the exhaustion of hydrogen in part or all of the star, and the star might be compelled to use some less well-regulated reaction for energy generation; and it is well known that nuclear reactions which get out of hand can have devastating results! (R.G.)

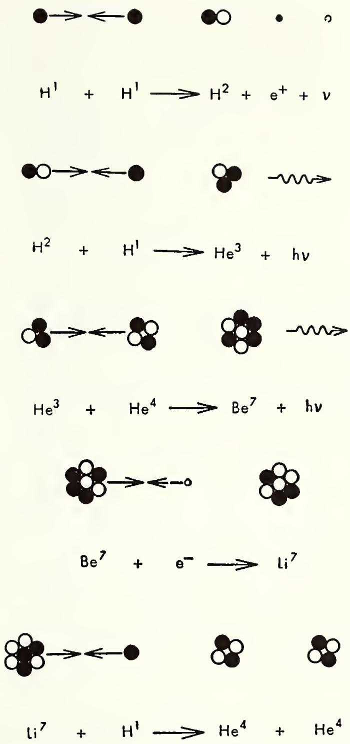
SUBGIANT. A star appreciably but not greatly larger and brighter than a main sequence star of the same spectral type. See **Hertzsprung-Russell Diagram.**

SUN. The Sun is by far the closest star to the Earth, its nearest rival being more than a quarter of a million times further away. It is the only star which presents an appreciable disc in a telescope, and consequently our knowledge of the Sun is much more detailed than that of any other star.

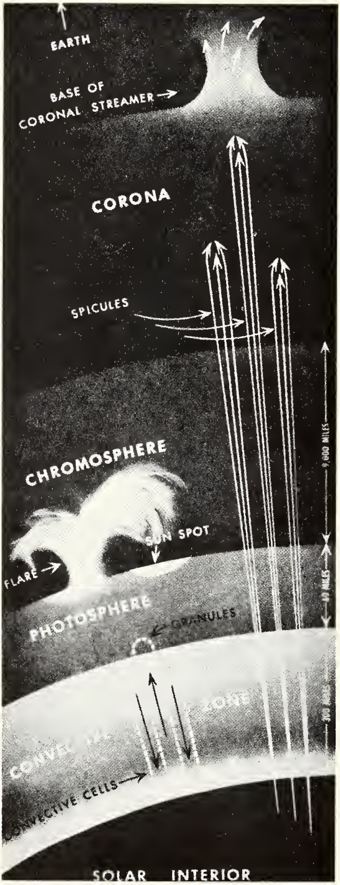
The Sun presents a disc a little over half a degree of arc in diameter. Its distance is 93,000,000 miles on the average; its diameter is some 860,000 miles. The solar mass is just about a third of a million times that of the Earth or 2×10^{33} grams. The surface gravity on the Sun is about 28 times that on the Earth, and this causes great compression of the material comprising the Sun, so that its average density is about 1.4 times that of water. The high surface gravity is also partly responsible for the sharpness of the Sun's limb as seen in a telescope.

Our luminary is a very undistinguished star, a vast sphere of glowing gas; it is a very typical dwarf star of **spectral class** G 2, and is represented by a point lying neatly on the Main Sequence of the **Hertzsprung-Russell Diagram.** Its apparent stellar magnitude is a little fainter than —27, and the absolute magnitude of + 4.7 follows from this. The Sun's internal structure and source of heat are discussed under the heading of **Stellar Energy.**

When we observe the Sun through a telescope (with, of course, suitable arrangements for dimming its light to a comfortable value) we see no solid surface but just the outer layers of a sphere of gas. The gas



THE PROTON-PROTON REACTION. The nucleus of a hydrogen atom is a single proton (black circles). By successive collisions and the release of some energy these protons can coalesce to form Helium nuclei (i.e. alpha particles) each containing two protons and two neutrons (white circles). As this process continues in stellar interiors, hydrogen is used up, helium becomes more abundant, and energy is released. Only when the hydrogen supply fails can a star begin to cool.



Opposite:

THE VEIL NEBULA IN CYGNUS. Some 50,000 years ago a supernova exploded, shooting out gases at a speed of thousands of miles per second. These gases are still rushing outwards, at about 75 miles per second. Their atoms become ionized in collisions with atoms of interstellar matter, and the ionized cloud fluoresces under irradiation from nearby hot stars against the background of the Milky Way.

By sweeping up interstellar matter, the cloud has greatly increased its original mass. In 25,000 years it will have faded away.

This picture is one of several taken by William C. Miller at Mount Palomar Observatory. Even when armed with powerful telescopes, the human eye can detect virtually none of the glowing colours in this photograph, as it is insensitive to colour in very faint light. Exposures of many hours on specially fast colour film, followed by corrections to cancel the film's varying efficiency in different colour ranges, can produce pictures such as this one, which are as true as modern photographic techniques permit.

A black-and-white picture of the Cygnus nebula is given on p. 119.

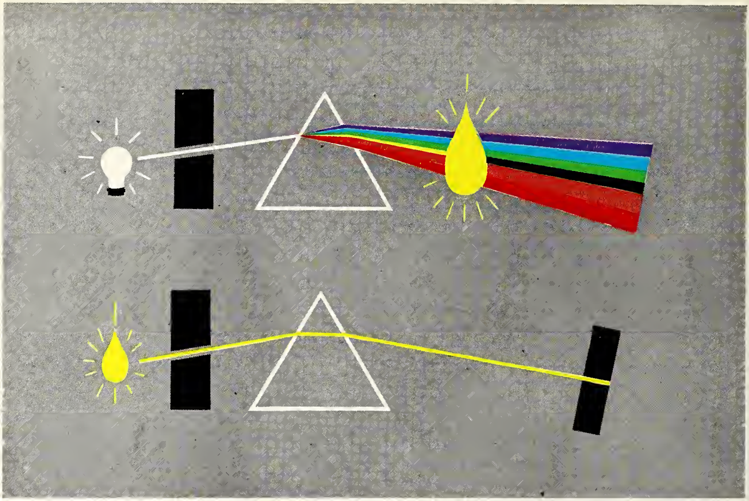
(*Mount Wilson–Palomar and National Geographic Society.*)

contains many **ions** which make it opaque when seen in any great thickness, so we cannot see regions of the Sun many miles below the 'surface'. The surface layers of the Sun are called the *photosphere*. Above the photosphere lies a tenuous, and for the most part transparent, atmosphere. The lower part of the solar atmosphere is the *chromosphere*, about 10,000 miles deep and merging into the higher *corona*, which extends several millions of miles from the Sun.

The photosphere presents a picture of ceaseless activity and motion. It often has areas of intense disturbance centred round dark markings known as *sunspots*.

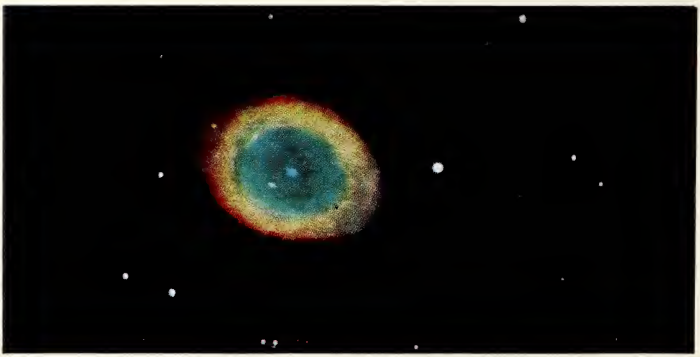
SUNSPOTS are areas where the temperature of the photosphere is abnormally low. The average photospheric temperature is around 5,500° C., while sunspot temperatures are about 4,000° C. Spots are of all sizes up to (exceptionally) 100,000 miles or more across. The smallest are called *pores*.

Typical sunspots have two well-defined areas: a dark *umbra*, surrounded by a less dark *penumbra*, which shows a great deal of fine striation and other structures. Spots often occur in groups which are extended in longitude more than in latitude, and there are often two large spots, one at either end of the group, which are named leader and trailer spots; between these, there may be as many as

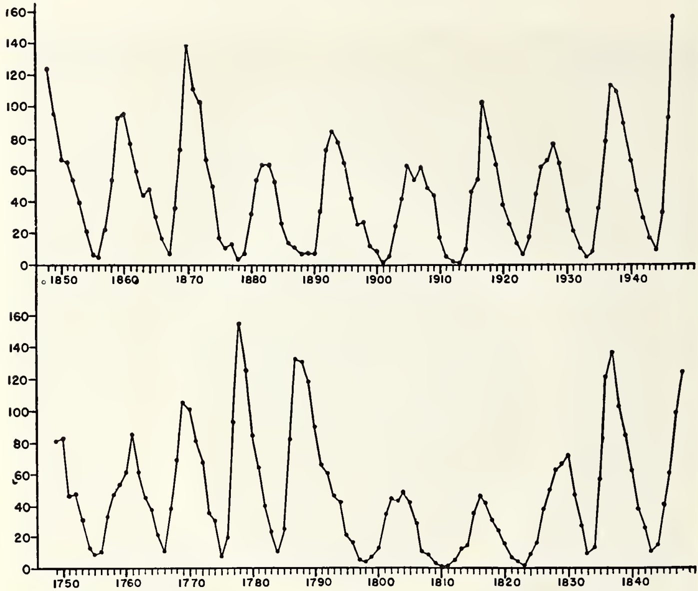


Above: EMISSION AND ABSORPTION SPECTRA. The glowing filament of the lamp emits white light. The beam which passes through the slit is refracted by the prism into a continuous spectrum. The yellow sodium flame absorbs light of those wavelengths which the flame itself emits in all directions, and a black absorption band shows in the spectrum. If the glowing gas of the flame is used as the light-source, the yellow sodium line appears in the place of the absorption line, and most other wavelengths are absent. See p. 242.

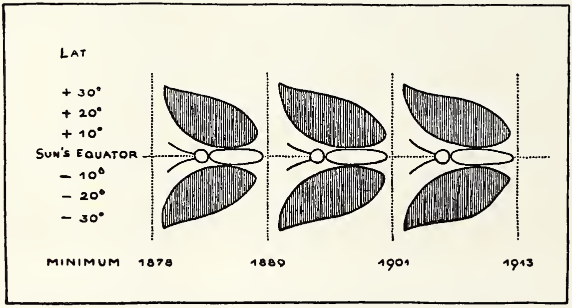
Below: THE OWL NEBULA, photographed in colour by W. C. Miller of Mount Palomar Observatory. The colours indicate a decrease of temperature towards the outside edge. See p. 249.



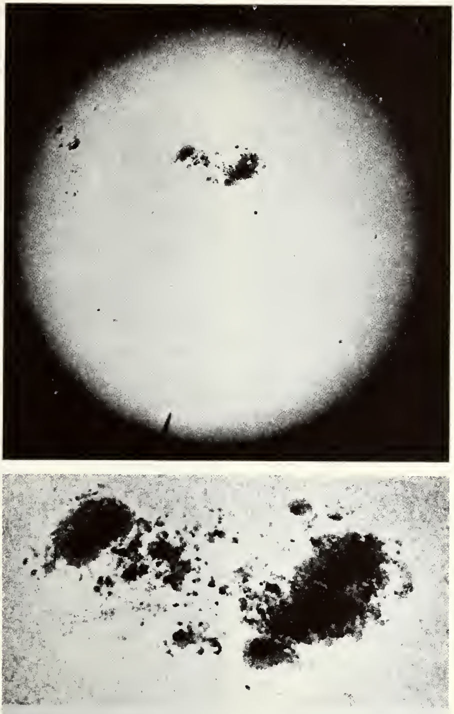
THE CORONA OF THE SUN IN ECLIPSE. The whip-like coronal streamers can be seen to fan out near the upper right and lower left rim of the Sun. An irregularity in the outline of the Moon which obscures the Sun can just be detected on the extreme right.



THE SUNSPOT CYCLE, 1749–1948. The average interval between maxima is 11.2 years. (*Menzel*)



THE BUTTERFLY DIAGRAM. The shaded areas extend over the range of latitude in which sunspots were observed at any given time. For instance, in 1881 all spots were between + 15° and + 28° and between — 16° and — 31°. The dotted vertical lines indicate the sunspot minimum at the end of each 11-year cycle. The body and feelers of the 'butterfly' have been added only to complete the pattern.



The Sunspot of April 7, 1947

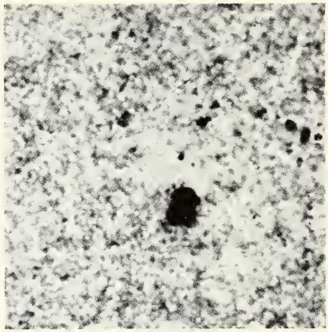
a few dozen smaller spots, often enveloped by the same penumbra. The lifetime of sunspots is very variable: small spots and pores last a few days, or even less than a day; larger spots and groups last up to 100 days.

THE SUNSPOT CYCLE. The spottedness of the Sun varies markedly. The spottedness is sometimes given in millionths of the visible hemisphere. The largest group on record was seen in April, 1947, and had an area of 6,100 millionths. But the customary system uses WOLF RELATIVE NUMBERS, which take account of the number of spots and groups, and the observer's instrument. When the mean sunspot number for each year is plotted on a graph, the latter shows a very obvious cycle of about 11 years; the length of time between successive maxima varies from 7½ to 16 years. The rise to sunspot maximum is normally more rapid than the decline. The annual sunspot numbers from 1750 to 1948 are shown opposite.

SUNSPOT LATITUDES. Sunspots are only found within 40° of the solar equator, and the mean latitude varies during the sunspot cycle. Shortly after minimum the spots occur in the higher latitudes on both sides of the equator, and as the cycle progresses they move gradually into lower latitudes, nearly reaching the equator by the time sunspot minimum is again reached, and new spots break out in high latitudes. This is pleasingly portrayed in the 'Butterfly Diagram'.

FACULAE. These are brighter patches of the photosphere usually associated with sunspots. They sometimes appear on the solar surface before a spot in the same region, and often persist after the disappearance of spots.

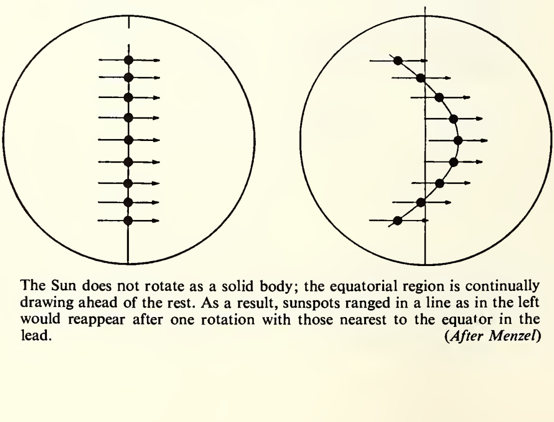
GRANULES. The photosphere shows structure not only in and around sunspots, but everywhere except close to the limb. It is covered with a system of *granules*, which give the surface a mottled effect. Individual granules are only about one second of arc across, and are difficult to see, let alone photograph. In the 1880s the French astronomer Janssen secured some amazingly good photographs of granules which have seldom been surpassed, despite the great technical advances in both instrumentation and photographic techniques since Janssen's day. The bright granules seen in the photograph are the tops of convection currents bringing up hotter material from below, while in the dark intervening lanes cooler matter is subsiding.



SUNSPOTS AND SOLAR GRANULATION. The fine mosaic-like pattern is difficult to reproduce in print; it represents the tops of the convective cells. (*Janssen, Meudon*)

Any particular granule is only visible for a few minutes.

ROTATION. From the movement of sunspots, we know that the Sun rotates on an axis inclined at 83° to the ecliptic in about a month. The exact time varies with the latitude, being shortest at the equator. At latitudes above 40°, the Doppler effect caused by the approach and recession of opposite limbs has



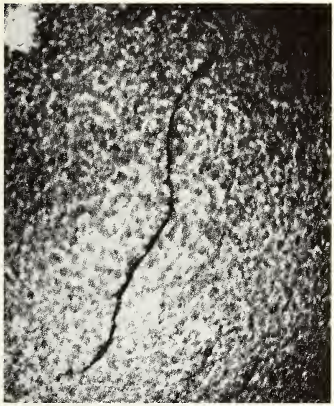
The Sun does not rotate as a solid body; the equatorial region is continually drawing ahead of the rest. As a result, sunspots ranged in a line as in the left would reappear after one rotation with those nearest to the equator in the lead. (*After Menzel*)

to be used to find the rotation period. The table gives the period at different latitudes.

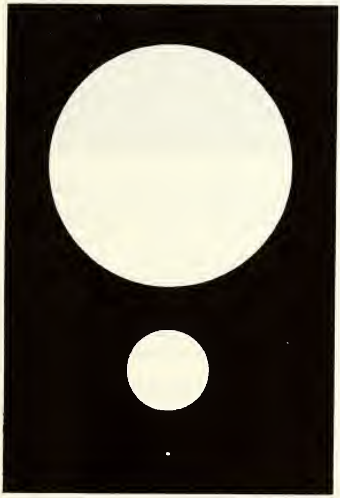
PERIODS OF SOLAR ROTATION.

Latitude (*degrees*)	*Period* (*days*)
0	24.65
20	25.19
40	27.48
60	30.93
90	34

The rotation is in the same direction as the movement of the Earth round the Sun. Consequently the period appears about two days longer from the Earth. Spots take a fortnight to cross the disc, and if very long-lived they reappear at the east limb a fortnight after passing round the west limb.



SOLAR FILAMENT of July 20, 1922 – one of the largest on record. A flocculus appears at top left. (*d'Azambuja, Meudon*)



Relative sizes of the Sun as seen from Mercury, Mars and Neptune. Approximately correct diameters will be seen if the book is put about $4\frac{1}{2}$ feet away.

CHROMOSPHERE. The lower part of the Sun's atmosphere is responsible for the absorption spectrum. The photosphere radiates nearly as a black body and gives a continuous spectrum; atoms in the chromosphere absorb the specific wavelengths of light which they require to become excited, and give rise to the many thousands of dark absorption or Fraunhofer lines which cross the solar spectrum (see **Spectroscopy**). The lines are all identifiable with elements found on Earth; more than sixty elements have been recognized in the Sun. Hydrogen is far and away the most abundant of the constituents of the Sun. The region of the chromosphere in which the absorption or 'reversed' lines are found used to be termed the *reversing layer*; this name has been dropped as it is now known that not all the lines are formed at the same height in the chromosphere.

The chromosphere has also a feeble emission spectrum, but when the photosphere is visible its overpowering light masks the chromospheric emissions. However, at the time of a total eclipse, the chromosphere only is seen at the initial and final moments of totality, and at these times the so-called

flash spectrum can be obtained. The flash spectrum is very similar to the absorption spectrum in reverse, but surprisingly enough shows the temperature of the chromosphere to be higher than that of the photosphere.

sphere near the Sun's poles; each lasts a few minutes only. Together they cause the chromosphere to appear like a lawn viewed horizontally, with many grass blades sticking up. They may be related to granules.

The great solar prominence of June 4, 1946. The round, white dot indicates the size of the Earth. When this picture was taken the arch of the prominence was shooting outwards with a speed of over 100 miles per second. Less than two hours later it had dissipated itself. (*Roberts, Climax*)

PROMINENCES. These are seen during total eclipses as purple appendages of the chromosphere. They are huge clouds of glowing gas, of diverse forms which change continuously. Some are quiescent, remaining almost the same for hours; many are arched, and are shot off the chromosphere with great velocities; there are also geyser-like eruptions and other forms. Some types are associated with sunspots. Speeds of over 100 miles per second are observed, and exceptional prominences are thrown several hundred thousand miles above the Sun.

SPICULES are like tiny prominences: glowing tongues of gas which shoot out of the chromo-

The **coronagraph** enables spicules and prominences to be observed without a total eclipse; but for its aid very little would be known about these features.

SPECTROHELIOGRAPH. This instrument enables us to observe the Sun in light of one colour only. If the colour is chosen to be exactly that of an absorption line the instrument 'sees' only the atoms of the kind which are forming the line, and a photograph showing the distribution of these atoms is obtained. The most usual absorption lines to use are the red line of hydrogen, designated Hα, and the violet line of ionized calcium. Approximately the same structures are seen whatever

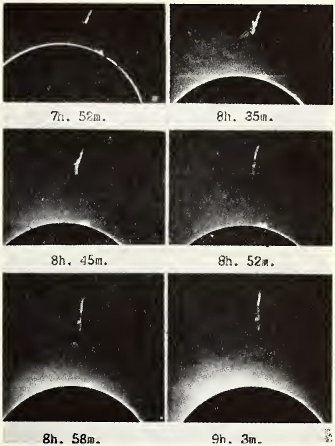
line is observed. The layers depicted lie in the lower parts of the chromosphere and show a mottled structure, far coarser than granules. Bright regions often occur; these are called *flocculi*. Dark markings called *filaments* are prominences seen in projection against the solar disc instead of against the sky beyond the limb. Near the centre of the disc filaments appear very narrow, showing that prominences are thin, blade-like sheets of gas.

FLARE. This is a sudden, short-lived increase in the light intensity of the chromosphere in the vicinity of a sunspot. It is normally seen in Hα light, using a spectrohelioscope, but very intense ones can be observed in white light, as was first done in 1859. Flares are bursts of *light*, not of matter. They have great influence on the Earth.

CORONA. This is the outer part of the solar atmosphere and is composed of exceedingly tenuous gas. Although the innermost parts can be revealed by the coronagraph, the corona can only be well observed during the fleeting moments of a total eclipse. Then it is seen as a shining halo of white light, decreasing in intensity away from the Sun until it is lost against the remaining brightness of the sky. The total light is less than that of the full Moon. The corona has on occasion been seen to extend as far as five solar diameters from the Sun. Its form varies markedly with the sunspot cycle: at sunspot minimum it has long equatorial streamers and short polar plumes, while at maximum it is much more nearly circular. Radial structures and streamers are always noticeable.

The spectrum of the corona is complicated and puzzling. It points to the existence of three sources of light:

(i) An emission spectrum, whose source has been called the E corona. The bright lines were at first unidentifiable, and were attributed to a new element, 'coronium'. It transpired that they are emitted by common atoms such as iron, nickel and calcium, ten to thirteen times ionized. Such ionization could only occur at stupendous temperatures of the order of a million degrees Centigrade! The emission lines are only seen in the spectrum of the *inner* corona.



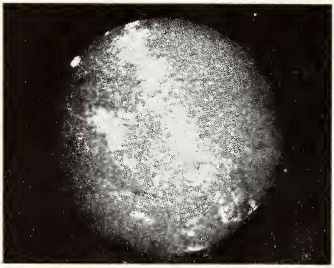
A very high eruptive prominence on the Sun.
(*Royds, 1928*)

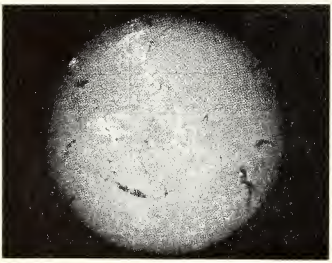
(ii) The solar absorption spectrum; this must be seen by reflections from particles in the corona. These presumably constitute the innermost zone of the Zodiacal Light, and their light, called the F corona, dominates in the region beyond one solar diameter from the limb of the Sun.

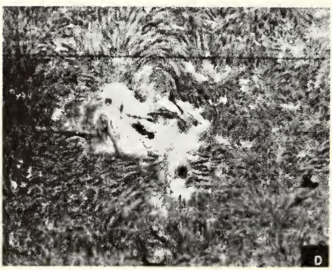
(iii) The K corona, dominating near the Sun, shows a solar type spectrum with immensely widened absorption lines. It is due to sunlight scattered by free electrons whose motions at a temperature of 1,000,000° C. would account for the extreme Doppler broadening (see **Spectroscopy**).

RADIO EMISSIONS from the Sun are discussed in the article on **Radio Astronomy**. They emanate from the corona and corroborate the extreme temperature suggested by spectral observations.

MAGNETIC FIELD. Conflicting results were obtained regarding the general magnetic field of the Sun until the recent invention of the







THE SUN. From top to bottom: (1) ordinary photograph, (b) calcium spectroheliogram, (c) hydrogen spectroheliogram, (d) enlarged portion of (c) showing details of the sunspot group.
(*Mount Wilson – Palomar*)

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magnetograph, which has shown that a small field exists but is only discernible in the polar regions.

Large and readily measured magnetic fields of up to a few thousand gauss are associated with sunspots. The flare photograph shows typical alignment of material in such a field. Leader and trailer spots in a group are of opposite magnetic polarity. The polarities in a spot group in the opposite hemisphere are reversed, so that if the leader spots are north poles in the northern hemisphere they are south poles in the southern hemisphere. The polarities in the hemispheres are interchanged when the spots of a fresh cycle break out in high latitudes so that the sunspot cycle is really 22, not 11, years.

Most of the magnetic phenomena observed on the Sun may be explained by postulating two magnetic fields in the shape of irregular loops, one in each hemisphere, which occasionally reach to the surface but for the greater part lie in the interior.

EFFECTS OF THE SUN ON THE EARTH. Apart from the grosser effects such as the retention of the Earth in its orbit and the supply of energy equal to that of a few thousand atomic bombs every second, the Sun influences conditions on the Earth in a number of ways. Magnetic storms, aurorae, and the disruption of short-wave radio communications occur as a result of the entry into the upper atmosphere of charged particles shot out from flares. Flares also seem to be able to generate **cosmic rays**. The relationship between flares and terrestrial phenomena is to be minutely investigated when the results of the International Geophysical Year are available for discussion. (R.G.)

SUNSEEKER. A photo-electric apparatus in the nose-cone of a rocket which causes a section of the instruments to be directed constantly towards the Sun despite tumbling

A partial eclipse of the Sun. (*Kearons*)

and rolling of the rocket in flight. It provides the stable platform necessary for long exposure photographs.

SUNSPOT. A relatively cool portion of the photosphere of the **Sun**.

SUPERGIANT STARS. Stars of enormous size and luminosity compared with main sequence stars of the same spectral type. See **Hertzsprung-Russell Diagram.**

SUPERNOVA. A star which explodes catastrophically, with a sudden liberation of most of its energy.

A supernova has a light curve superficially like that of a normal **nova** with a rather slower accession of brightness and a smoother decline, uninterrupted by irregular fluctuations. However, the scale of the phenomenon is quite different, a supernova being about ten thousand times as bright as an ordinary

SUPERNOVA in an irregular galaxy. *Top:* 1937 Aug. 23, exposure 20 min., maximum brightness. *Middle:* 1938 Nov. 24, exposure 45 min., supernova faint. *Bottom:* 1942 Jan. 19, exposure 85 min., supernova too faint to observe. Only the last exposure was long enough to bring out the galaxy itself. (*Mount Wilson – Palomar*)

nova. The absolute magnitude of a supernova at maximum is around -16 or -17; it releases as much energy in one second as the Sun does in 60 years.

Unfortunately supernovae are rather rare and difficult to study. Even in a large galaxy such as our own the frequency is only a very few per millenium. The only historical supernovae observed in our Galaxy occurred in 1054, 1572 and 1604; all reached apparent magnitudes considerably brighter than zero, and that of 1572 was clearly visible in daylight. About fifty have been observed in other galaxies.

A supernova outshines the whole light of any but the largest galaxies. One photographed in the thirteenth-magnitude galaxy IC 4182 outshone the galaxy by five magnitudes – a hundredfold!

There appear to be two types of supernova. Type II seem like novae on a grand scale: they have recognizable spectra which are quite similar to those of novae, and are rather fainter than Type I. Their rates of expansion are around 5,000 km/sec. Type I have entirely unrecognizable spectra in which not a single band has been identified. The widths of the bands suggest explosive velocities in excess of 10,000 km/sec.

It seems that a supernova explosion results in the dissipation of nearly the whole mass of the star into space, and therefore it can happen only once to a star, in contrast to nova outbursts. The remains of the supernova of 1054 are still visible as an irregular, expanding nebula (the **Crab Nebula**) consisting of matter propelled outwards from the star by the explosion. The remnant of the star itself is visible as a peculiar object of the sixteenth magnitude, a decrease of twenty magnitudes or a hundred-million-fold from its maximum. Its spectrum suggests a dwarf star with the amazingly high surface temperature of half a million degrees Centigrade.

Nothing is known about the cause of these cataclysms. (R.G.)

SYNODIC PERIOD. The interval between successive oppositions of an outer planet, or between successive inferior conjunctions of an inner planet. (See **Conjunction**.)

SYRTIS MAJOR. The most conspicuous dark area on **Mars**. It is visible in a small telescope when Mars is well placed.

T

TAURIDS. A **meteor** shower with maximum activity during the first ten days of November.

TELEMETRY. The technique of transmitting information from rockets or balloons in flight above the Earth to a ground station. See **Rocket Instrumentation**.

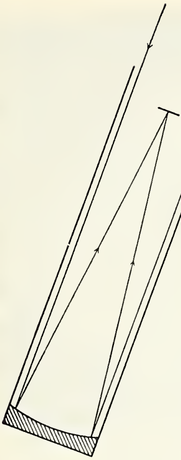
TELESCOPE. (The reader is asked to refer to **lens** and **mirror** before reading this article.) A telescope is an optical instrument used for examination of distant objects. It consists of two components: a lens or mirror capable of gathering light from the distant object and focusing it into an image which is a miniature of the object; and an **eyepiece** which magnifies the image.

REFRACTORS AND REFLECTORS. Telescopes which employ a lens or *object-glass* to form the image are termed *refracting telescopes*, or simply *refractors*. The object-glass is made up of two lenses; this is essential to minimize **chromatic aberration**.

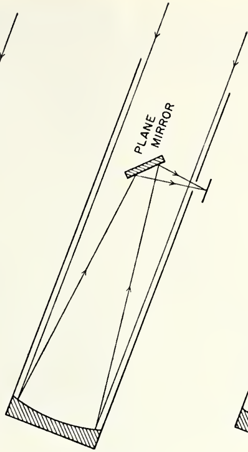
If a mirror is used to form the image instead of a lens, the result is a *reflecting telescope*, or *reflector*. As the image in a reflector is formed between the mirror and the object under observation, if one attempted to view it *in situ* one's head would obstruct the incoming light. Various systems have been devised to overcome this; most employ a small secondary mirror to deflect the light and cause the image to be formed in a more convenient place. The commonest system for small reflectors is the *Newtonian*: a small flat mirror, always called simply the *flat*, is set at an angle of 45° in the telescope tube and reflects the light out to an eyepiece at the side.

Large reflectors often use a convex secondary mirror which reflects the light through a hole in the main mirror; this is the *Cassegrain* system.

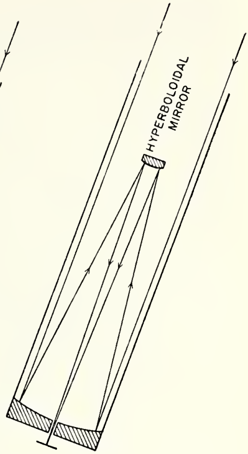
Other systems are frequently used on large reflectors; sometimes a number of secondary



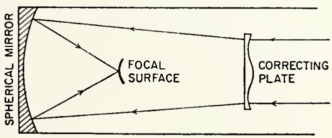
PRIME FOCUS



NEWTONIAN



CASSEGRAIN



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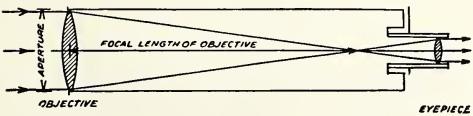


Refracting Telescope

mirrors are employed alternatively to give images in different places.

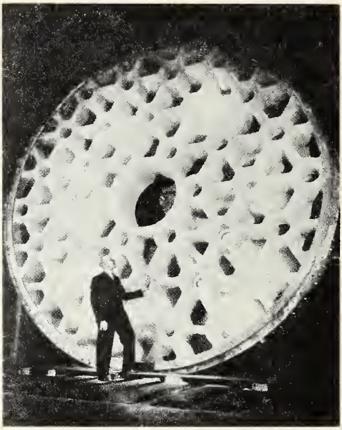
Of course, the secondary mirror, or other obstruction, is not seen in the eyepiece because this is focused on the image and not on the mirror.

APERTURE, LIGHT-GRASP AND RESOLVING POWER. The *aperture* of a telescope is the diameter of its main mirror or lens. The chief task of a telescope is to gather as much light as possible; the greater the aperture, the more light is collected, and the fainter the stars that can be seen. This power of a telescope to collect light is sometimes called its *light-grasp*. The table gives the approximate limiting magnitudes of stars visible on a first-class observing night with various apertures:

Aperture (inches)	*Magnitude*
1	9.5
2	11.0
3	12.0
4	12.6
6	13.5
12	15.0
30	17.0

The *resolving power* of a telescope is the smallest angular distance between two stars for them to appear just separated in the telescope, in favourable circumstances. This angle is inversely proportional to the aperture of the telescope. Theory and practice agree that it is about five seconds of arc divided by the aperture in inches.

MAGNIFYING POWER depends upon the eyepiece used, and can be almost any desired value. The answer to the question 'How powerful is that telescope?' cannot therefore be given in terms of magnifying power, but rather in terms of light-grasp. Great magnification is not necessarily an advantage. It is obviously useless to magnify an image beyond the point at which the telescope's limited resolution causes it to appear ill-defined; this point is reached when the power is about 50 times the aperture of the telescope in inches. Thus the best 6-inch telescope in the world cannot magnify with clarity more than + 300.

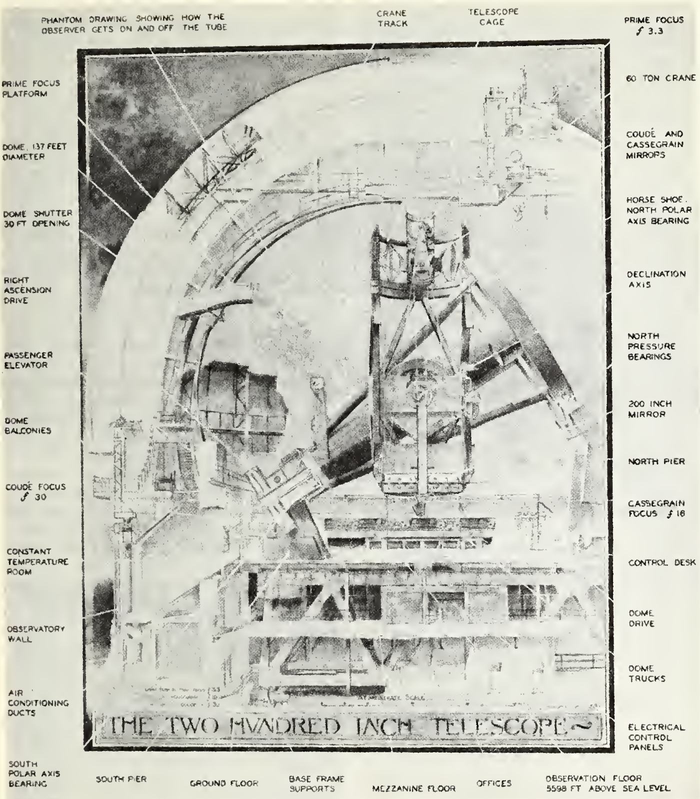


THE BACK OF THE 200-INCH MIRROR. It was cast in Pyrex glass, and 10 years were spent in letting it cool evenly and grinding its optical surface. The honey-comb spaces reduce the weight of the mirror by 20 tons, and enable it to follow changes in atmospheric temperature far more rapidly than a solid mirror.

Often, the **seeing** limits the reasonable magnification to a much lower value. In any case, a high power has the disadvantage of giving a small **field of view**, so that observations of extended objects such as star clusters and nebulae are generally best carried out with a low power, of 6 to 10 per inch of aperture.

DESIGN OF TELESCOPE TUBES. A refractor invariably has a cylindrical tube with the object glass at one end and the eyepiece at the other. A reflector, however, must have a tube open at the 'top' to let light pass down to the mirror at the far end, and the tube design is a matter of choice. The essential function of the tube is simply to keep the mirrors and eyepiece in the correct relative positions; it need be not more than a framework.

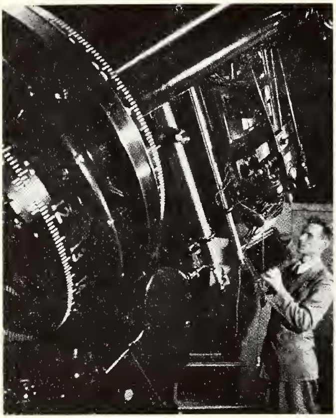
Large reflectors housed in observatory buildings very often have lattice-work 'skeleton' tubes made of steel struts. Smaller ones used outdoors also sometimes have lattice



A cut-away diagram of the 200-inch telescope and its housing. (*Mount Wilson – Palomar*)

tubes, but these allow dew to form on the mirrors, and extraneous light from nearby, or from the Moon, enters the eyepiece and spoils the image. The remedy is to make the tube of sheeting, instead of isolated bars.

Unfortunately reflectors, necessarily having one end open, are very prone to air currents which flow up and down the tube, refracting light irregularly and giving an unsteady image (see **Seeing**). If the tube is a mere framework, the currents cannot flow along it; in a tube made of sheeting they can be very troublesome. A large hole in the side of the tube near the main mirror prevents cold air collecting



Loading a photographic plate into the 15-inch refracting telescope at the U.S. Naval Observatory.

at the bottom of the tube. Making the tube out of heat-insulating material prevents rapid changes in temperature inside and helps to minimize air currents: thus wood is preferable to sheet metal, or a metal tube may be cork-lined. If the tube is of square section, the currents tend to flow in the corners wherethey are least harmful; circular-section tubes have no such advantage.

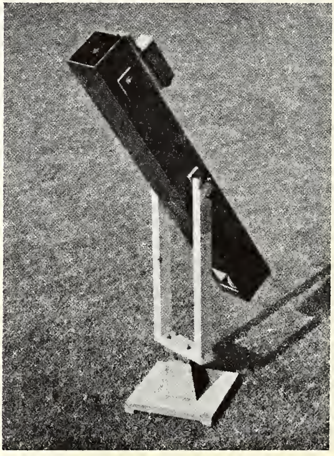
TELESCOPE MOUNTINGS. There are two systems of mounting – altazimuth and equatorial.

An *altazimuth* mounting allows the telescope to move in two directions, vertically (altitude) and horizontally (azimuth). This type of mounting is easily made by amateurs and can readily be made portable.

The *equatorial* mounting carries the telescope about an axis which points towards the celestial pole and is therefore parallel with that of the Earth. The Earth rotates one degree in four minutes, so that frequent adjustments must be made to the position of a telescope to prevent the object under observation drifting out of the field of view. An altazimuth mounting requires corrections in both altitude and azimuth, but the equatorial needs only to be turned about one axis to follow a particular star. As the Earth turns, the equatorial is turned about its parallel axis in the opposite direction; this can be done continuously and automatically by a clockwork drive, and the observer's hands are left free. The axis parallel to the Earth's is called the *polar axis*; there is also a *declination axis* which enables the telescope to be trained on objects at any distance from the celestial pole.

The *English* type of equatorial has the telescope pivoted in declination inside a rectangular frame or yoke which is pivoted at the polar axis. The 100-inch reflector at Mount Wilson is mounted in this way. It has the disadvantage that the end of the yoke obstructs the instrument's view of the celestial pole, and the 100-inch cannot get above +56° declination. For the 200-inch at Mount Palomar, this system was modified, and the upper bearing hollowed out as a horse-shoe between whose arms the telescope can swing to reach the pole.

A home-made Newtonian reflector of six inches aperture. It has a wooden tube and an altazimuth mounting. A portion of the mirror is seen at the lower end of the tube; near the top is the eyepiece, and above it the finder. (*R. Grifin*)



The *fork mounting* has the polar axis bifurcated above its upper bearing, and the telescope turns in declination within the fork so formed. The 48-inch Schmidt on Mount Palomar is so mounted, and the 120-inch reflector at Lick is supported in the same way.

The *German* equatorial has a declination axis above the upper bearing of the polar axis; the telescope is mounted at one end of the declination axis, and a counterweight at the other.

The three varieties of equatorial mounting described above are by no means the only practicable forms, but they are the most common and are used for the majority of the telescopes in the world's observatories.

TELESCOPE HOUSING. Large telescopes are always housed in some sort of building. Occasionally, the building or its roof are removed a short distance upon rails when the telescope is used, but generally the roof is a hemispherical dome provided with a shutter; this can be moved to leave a slit through which the telescope is pointed. The dome can rotate above the circular wall of the observatory to allow the telescope to be used in any direction. (R.G.)

TEMPERATURE. The degree of hotness of a body, as measured by one of several arbitrary scales; it is proportional to the average kinetic **energy** of the molecules in the body.

Very tenuous matter, such as that composing the exosphere, may have a very high temperature but contain little heat. The individual atoms possess large kinetic energies and the gas is therefore by definition at a high temperature. However, the gas is so rarefied that the amount of heat contained in a given volume is relatively small. A cupful of water at normal temperature contains more heat than forty thousand cubic yards of the outer atmosphere at 2,700° C. Conduction of heat ceases to be effective in a tenuous gas as collisions between atoms become rare.

The temperature of an empty space depends upon the radiation passing through it, and is the temperature which a **black body** would reach if placed in the space. (See **Heat**.)

TERMINATOR. The boundary between the daylight and night hemispheres of a planet or satellite.

In the case of the Moon, the terminator appears rough and broken owing to the unevenness of the lunar surface. Irregularities have also been seen in the terminator of Venus, but are probably due to phenomena in the atmosphere of that planet.

THERMOCOUPLE. An instrument used to detect and measure radiant heat. It consists of a junction or contact between two wires of dissimilar metals. A voltage is set up between them, and its amount depends upon the temperature. If there are two such junctions connected in an electrical circuit in such a way that their voltages act in *opposite* directions, there is no nett voltage if their temperatures are the same. A minute amount of radiant heat falling on one of the junctions causes a disparity between the opposing voltages and a small nett voltage remains, which is easily detected by a sensitive **galvanometer**.

THREE-BODY PROBLEM. Given three bodies of known masses, their positions in space at any one instant and the speed and direction of their motions, is it possible to calculate what their positions will be after a given interval of time, if the only forces acting on them are the gravitational attractions between them? The laws governing these attractions are fully known, and in the case of two bodies present no special difficulties. For three or more bodies the problem has, however, so far proved insoluble unless (1) the three bodies form an equilateral triangle as in the case of the Sun, Jupiter and the **Trojans**, or (2) one of the bodies is very small compared with one of the others, e.g. in the Earth-Moon-Sun system, or (3) the three bodies are ranged in a certain way along a straight line. In all other cases, practical answers can only be found by a laborious step-by-step method of approximation. Modern computing machines facilitate this kind of calculation, but the full general solution remains one of the outstanding problems of celestial mechanics.

THRUST. The propelling force exerted on a rocket by its exhaust jet.

TIDAL FRICTION. The force tending to slow down the rotation of one body in the gravitational field of another.

As the Earth rotates 'beneath' the Moon, water is heaped up under the latter; this bulge remains always in the same place relative to the Moon and the Earth therefore rotates under it. This effect is the cause of the ocean tides. The friction of the tides on the Earth is overcome only by the continuous expenditure of about two thousand million horsepower derived from the rotational energy of the Earth which has, however, a large store of it. The length of the day is being increased by this tidal friction by about a thousandth of a second per century.

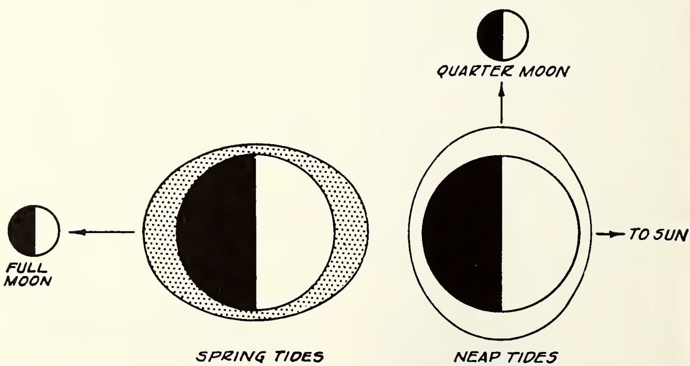
Smaller tides are also raised on the land and within the rotating bodies even if they have no liquid on them. Work is done in deforming a body to raise tides, and this work comes from the rotation. The rotational energy of all the satellites in the solar system has, as far as is known, been exhausted by tidal friction, so that they keep one face permanently turned towards their primaries.

TIDES. The tides on the Earth are caused by the rotation of our planet in the **gravitational fields** of the Sun and Moon; the ability of the Moon to raise tides (its *tide-raising force*) is nearly three times as great as the Sun's.

The gravitational field of the Moon, as of all other bodies, weakens with increasing distance; consequently the lunar attraction upon the Earth as a whole is weaker than upon the ocean immediately 'under' the Moon. This water therefore tends to be heaped up into a *high tide* by a flow of water from neighbouring areas. The flow constitutes the tidal currents. In a similar manner, the body of the Earth is attracted more than the waters on the side furthest from the Moon and is pulled away from them, causing a second high tide on the opposite side of the Earth from the first. As the Earth turns under these two tidal bulges, the latter pass any given point at intervals of little more than twelve hours, the Moon's motion accounting for the difference from the exact half-day. Owing to the friction of the seas upon their beds and shores, the time of high tide at a point on the coast differs from the time calculated from the position of the Moon.

Exactly similar considerations apply to the Sun, although the solar tides are less than those of the Moon. When the tidal bulges of the Sun and Moon coincide, at New and Full Moon, they have the maximum height and are called *spring tides*; at First and Last Quarters of the Moon, the two bodies are pulling at right angles to one another, and the *neap tides* which then occur have a relatively small range.

TIME DILATATION. The slowing-down of events taking place in one system as observed from another system, when the two systems are not at rest relative to each other, or are at different gravitational potential. This effect, which was predicted by the Theory of **Rela-**



tivity, is minimal except for velocities comparable to the speed of light, but is steadily receiving experimental verification.

TIME MEASUREMENT. The fundamental standard for time measurement has always been the period of the Earth's rotation, the day. All time-measuring instruments or clocks are intended to subdivide this period, so that the time of an event may be given accurately.

The first really efficient clocks were regulated by pendula. In theory they are perfect, but in practice many factors conspire to introduce errors: temperature changes alter the length of the pendulum, air pressure fluctuations alter the air resistance, and the pendulum must be periodically interfered with in order to keep it swinging. The *Synchronome-Shortt Free Pendulum*, which until recently was the standard at most of the world's observatories, overcomes some of these difficulties: it runs in an evacuated case at constant temperature, and is accurate to within one second per year.

Quartz clocks have improved on this for short periods. They have enabled us to detect slight changes in the length of the day during the year, a phenomenon which is caused by the locking up of great quantities of water as snow and ice in the polar regions during winter in each hemisphere.

There is promise of still better clocks for the future. These will depend upon the frequencies of vibration of atoms and molecules. Experiments using ammonia and caesium have already been carried out.

TIROS. Name of a family of American Television and Infra-Red Observation Satellites used for meteorological studies. See **Artificial Satellite**.

TITAN. The sixth satellite of **Saturn**. With a diameter of about 3,500 miles and an escape velocity of over 2 miles per second, it is the largest satellite in the solar system, and is moreover the only satellite definitely known to retain an atmosphere.

Also the name of a **missile**.

TRAJECTORY. The path described by a missile. See **Ballistics**.

TRANSDUCER. Any apparatus which converts physical quantities from one form into another. A microphone is a transducer, for example, since it changes fluctuations in air pressure (sound) into fluctuations of an electrical current; a tape recorder transduces sound into patterns of magnetization. Transducers of many kinds are used in rocket instrumentation and guidance.

TRANSFER ELLIPSE. The most economical path by which a rocket can transfer from an **orbit** about one planet into an orbit about another. It is part of an **ellipse** with the Sun in one focus. A rocket can travel in a planetary orbit without using propellents, as a planet. A relatively short burst of its motor can accelerate it into a transfer ellipse, and for the greater part of its journey the rocket moves part of the way around the Sun as an independent member of the solar system. By combining careful timing with a suitable acceleration or retardation upon reaching the second planet's orbit, the vehicle can then either land on it, follow it, or go round it and return to the first planet.

TRANSIT (*lit.* 'he crosses'). The passage of a planet across the Sun's disc, or of a star or other celestial body across an observer's meridian. See **Meridian Passage**, and p. 275.

TRANSIT CIRCLE. A telescope permanently aligned for the timing of transits. See **Meridian Passage**.

TRANSMISSION GRATING. See **Spectroscopy**.

TRITON. The larger satellite of **Neptune**. It has a diameter of perhaps 3,000 miles, and despite its distance is easily seen in a moderate telescope. It should be able to retain an atmosphere; indications of a methane mantle have been reported but not confirmed.

TROJANS. Several **asteroids** revolving in the same orbit as Jupiter; one group is 60° in front of Jupiter, the other 60° behind. Achilles and Patroclus, the largest members, are over 150 miles in diameter, but their remoteness makes them difficult to observe. The orbital motion of the Trojans is an example of an interesting special case of the **Three-Body Problem**.

TROPICAL YEAR. See **Year**.

TROPICS. The area of the Earth's surface over which the Sun can appear in the zenith. It is limited to the North by the *Tropic of Cancer* and to the South by the *Tropic of Capricorn*, the parallels of latitude 23° 27′ N. and 23° 27′ S. respectively.

TROPOPAUSE. The junction of the troposphere with the stratosphere. See **Atmosphere of the Earth.**

TROPOSPHERE. See **Atmosphere of the Earth.**

TWILIGHT. The periods after sunset, and before sunrise, when the sky is not dark. *Astronomical twilight* lasts while the Sun is less than 18° below the horizon; it lasts longer in high latitudes than near the equator because of the shallow angle at which the Sun sets and rises as seen from high latitudes. Twilight lasts all night around midsummer in Great Britain and areas further from the equator.

TWINKLING. The rapid changes in brightness and colour of stars, especially when at low altitudes above the horizon, due to **seeing** conditions.

U

ULTRAVIOLET RADIATION. Electromagnetic radiation emitted by very hot sources at wavelengths slightly shorter than those of light. The Sun is a powerful source of ultraviolet rays, but only a small proportion penetrates to ground level. At high altitudes, exposure to ultraviolet radiation can cause injury ranging from sunburn to blindness and wholesale destruction of tissue, but suitable clothing and shielding for the eyes easily provides protection.

Ultraviolet rays can be registered on photographic plates; they excite fluorescent substances into emitting light, and are responsible for a good deal of the ionization in the upper atmosphere. (See **Electromagnetic Spectrum.**)

UMBRA. When a source of light casts a shadow of an object, the shadow usually consists of two portions: the inner, dark *umbra*, which receives no light from the source, and the outer half-shadow or *penumbra*, which is illuminated by light from part of the source.

When the Earth enters the shadow of the Moon cast by the Sun, observers in the penumbra see a partial or annular eclipse of the Sun, and those in the umbra see a total eclipse. (See **Eclipse.**)

The word *umbra* is also applied to the darker region in a sunspot (see under **Sun**).

UNIVERSAL TIME is the time to which astronomical data are usually referred. It is the same as **Greenwich Mean Time.**

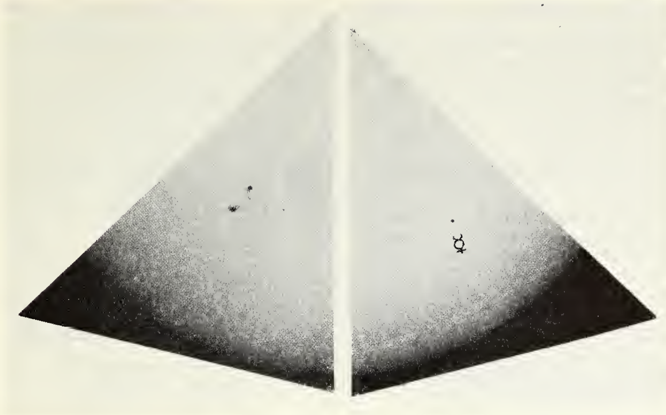
URANIUM. A chemical **element** whose atoms each contain 92 protons; this is the greatest number possessed by any naturally occurring element, although artificial elements have been made with up to 101 protons.

Uranium is radioactive metal, and is used as a fuel in nuclear reactors.

URANUS, the third of the giant planets, was discovered in 1781 by Sir William Herschel. Herschel was not, however, the first to record it; Flamsteed, the first Astronomer Royal, saw it six times between 1690 and 1715 without realizing that it was anything but an ordinary star. It is just visible to the naked eye.

ORBIT. Uranus revolves round the Sun at a distance which varies between 1,699 and 1,867 million miles, giving a mean of 1,783 million miles. The orbital eccentricity is 0.047, about the same as that of Jupiter; the inclination 0°.8, less than that of any other planet, and the mean orbital velocity 4.2 miles per second. The sidereal period is 84 years, so that Uranus has completed rather more than two revolutions since its discovery.

DIMENSIONS AND MASS. Uranus has a diameter of 32,000 miles, less than half that of Saturn. The volume of the globe is 64 times that of the Earth, the mass 15 times; the density is 1.3 times that of water, very slightly less than that of Jupiter. Oddly enough, the surface gravity on Uranus is less



A TRANSIT OF MERCURY. The small dot in the picture on the right is Mercury crossing the Sun's disc on November 7, 1914. On the left, a relatively small group of sunspots from a different part of the same photograph. (*Royal Greenwich Observatory*)

than that of the Earth (0.92), but the escape velocity is 13 miles per second.

ROTATION. The most remarkable feature of Uranus is the tilt of its axis, which lies almost in the place of its orbit. The 'seasons' there are in consequence most peculiar. First much of the northern hemisphere, then much of the southern will be plunged into darkness for many years at a time, with a corresponding period of sunlight in the opposite hemisphere. Sometimes, as in 1945, the pole appears to be in the centre of the disc as seen from the Earth; in 1966 ,the equator will be presented.

The rotation period is 10 hours 45 minutes, not much longer than that of Saturn. There is probably a difference between the equatorial and polar periods, but no certain information is available.

SURFACE FEATURES. Even a large telescope reveals very little detail on Uranus. Faint belts are sometimes visible, and occasional spots have been reported, as in 1949 and 1952; but all these are beyond the range of small or moderate instruments.

VARIANCE IN BRILLIANCE. Observations since 1951 have shown that the brightness of Uranus varies. Certain fluctuations are to be expected; when it is at its closest to the Sun the surface will be more brightly lit than when near aphelion, and owing to the polar compression a slightly larger apparent diameter will be presented when a pole appears central. The variations recorded are, however, additional to those of known cause, and it has been suggested that they are due to disturbances upon Uranus itself.

TEMPERATURE. Uranus is a bitterly cold globe. The temperature appears to be in the region of —185° C., appreciably lower than that of Saturn, and the satellite system must be equally frigid.

COMPOSITION OF THE GLOBE. In composition, Uranus is probably similar to Jupiter and Saturn. Spectroscopic research has revealed abundant methane and a trace of ammonia.

SATELLITES. The five satellites of Uranus, reckoning outwards from the planet, have been named Miranda, Ariel, Umbriel, Titania and Oberon. Estimates of their diameters are most uncertain. All are difficult objects – particularly Miranda, the closest to Uranus, which was discovered as recently as 1948. They revolve in orbits virtually in the plane of the planet's equator, and must be extremely cold worlds devoid of any trace of atmosphere.

TRAVEL TO URANUS. It seems hardly necessary to add that there is no prospect of reaching Uranus in the foreseeable future. The planet is even less welcoming than the nearer giants, and any form of life on it or its satellites seems to be out of the question, because of the low temperature (see **Life**). (P.M.)

URSIDS. A **meteor** stream with maximum display about December 22.

V

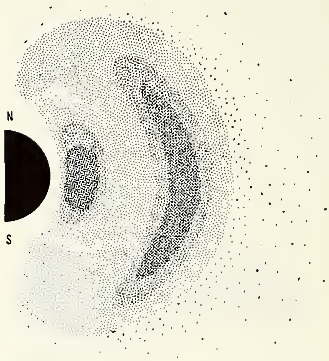
V-2. A ballistic missile used by Germany in the final stages of the Second World War. See **A-4.**

VACUUM. Space almost devoid of matter.

It used to be said that 'Nature abhors a vacuum'; but over 99.9999% of the known Universe is given over to a vacuum far better than any that can be achieved in a laboratory.

VAN ALLEN BELTS. Zones surrounding most of the Earth in the shape of shells in which charged particles are trapped and accelerated by the Earth's magnetic field.

The existence of these belts was deduced from data received from the Explorer IV artificial satellite and from rockets fired to 450 miles. In November 1958 a nuclear explosion took place at a height of 100 miles above the central Pacific; charged particles from this explosion travelled in a loop which spanned the equator, and produced spectacular aurorae on descending again near Samoa.



The radiation belt in which they moved was monitored by Pioneer III, and from the results Dr. Van Allen constructed a novel picture of the outer atmosphere. Prior to this Jacchia had inferred the existence of radiation belts from irregularities in the orbital decay of satellites. It was found that drag in the belts increased on the arrival of particles ejected by solar flares.

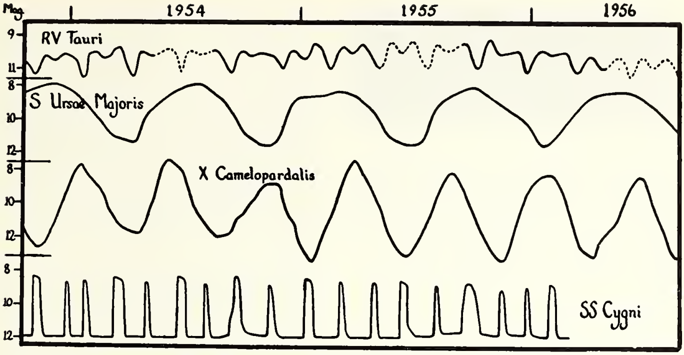
Two belts of fluctuating depth have been found in the region between 200 and 30,000 miles from the Earth. The outer belt curves down above the polar regions and is clearly related to auroral displays. Ionization by cosmic rays is probably the chief source of charged particles in the inner belt. The particles move in complicated spiral paths, and their high velocity imparts temperatures of over 2,000° C. to the belts.

The diagram above shows a section of the belts and half the Earth; the Earth's magnetic poles are marked N. and S., and the depth of shading indicates roughly the intensity of charged particle radiation.

VANGUARD. See **Artificial Earth Satellite.**

VARIABLE STAR. A star which varies in brightness, or **magnitude.**

NOMENCLATURE. In constellations where there are more naked-eye stars than could be



Light curves of four variable stars. The second and the third are long period variables; the curve for SS Cygni is typical of a class named after another of its members, U Geminorum. (*R. Griffin*)

named with the letters of the Greek alphabet, recourse was had to the small letters of the Roman alphabet, and finally to the capitals. The constellation richest in bright stars, Argo, used these up as far as Q. When variable stars were discovered, the first found in each constellation was named R, the next S, and so on to Z. Double-letter names were then given: RR, RS . . . . RZ, SS, ST . . . . SZ, TT . . . . ZZ. The later stars were designated AA, AB . . . . AZ, BB, etc.: at QZ this system too was exhausted, and numbers were given, the variable after QZ being V335, then V336 and so on.

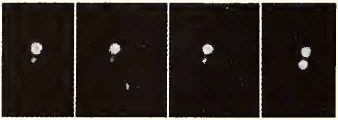
METHODS OF OBSERVATION. These are three in number:

(1). The magnitude of the variable may be estimated visually by comparison with other nearby stars of known and constant brightness; the accuracy of a careful observation is about one-tenth of a magnitude. This method is particularly suited to amateurs, and a large proportion of the observations made of variables which are not strictly periodic and have a range of variation, or *amplitude*, of the order of two magnitudes or more is made by them.

(2). The camera may be used. The diameters of star images on a photographic plate vary with the brightness of the stars; measurement of the image sizes enables magnitude determinations to be made to the same order of accuracy as by visual methods. Photography has the advantage of giving a permanent and objective record of the magnitude. A disadvantage is that the photographic plate and the eye do not have the same colour sensitivity: of two stars having equal visual magnitudes, the bluer one is brighter photographically. A suitable filter, however, may be used to bring photographic measurements into accord with visual ones: magnitudes determined in this way are called *photovisual.*

(3). A *photometer* attached to the telescope is able to compare the brightness of stars to considerably greater accuracy than the other methods, the error of an observation being of the order of a hundredth of a magnitude. This method of magnitude determination is slow and requires expensive apparatus.

CLASSES OF VARIABLE STARS. Observations of variable stars are plotted on graphs called *light curves* which show the variation of brightness with time. The shape of the light curve is of the utmost importance in deciding what type of star we are dealing with. The amplitude of variation and, in the



A FLARE STAR. Four photographs of the two close components of the multiple star Kruger 60, taken at intervals of about 135 seconds. There is a sudden and remarkable burst of luminosity from the normally fainter component. Flares like this are not uncommon among yellow and red dwarfs, and are basically similar to solar flares.
(*Sproul Observatory*)

case of a star with a repetitive light curve, the *period*, are also derived by inspection of the curve.

It is evident from the diversity of light curves that there are various types and causes of stellar variability. In some cases the curve is due to the eclipse of one star by another; in others there seems to be a periodic, or nearly periodic, oscillation of brightness of the star itself, while in yet others the light curve shows irregular, and in some cases very sudden, fluctuations. In the following paragraphs the characteristics of the main types of variables are described; the types are often named after the first-discovered star, which is known as the *type star*.

ECLIPSING VARIABLES. The light curves of these variables, and their importance in adding to our knowledge of the stars, are discussed in the article on **binary stars**. From the observational point of view, there are two chief types:

Algol stars, named after the type star Algol or β Persei, which was known as a variable by the Ancients who gave it its name meaning 'The Demon', have long, approximately horizontal portions of the light curve between minima. Amplitudes of variation up to four magnitudes are known, and periods range from about five hours to twenty-seven years. This longest period belongs to the naked eye star ε Aurigae; it is so large that, although the relative velocity of the component is nearly twenty miles per second, the eclipse lasts for two years! The last eclipse began in 1955. The light curve of the type star is shown in the diagram.

β *Lyrae* stars have continuously changing brightness. Chiefly hot stars of O, B and A types, they are close together and tidally distorted into elliptical shapes, so that a constantly changing area of star surface is presented to us. A secondary minimum is always observed. In a sub-class named after W Ursae Majoris the minima are equal; the periods of these stars are usually short, less than one day. β Lyrae stars are known with periods from one half to two hundred days.

CEPHEIDS are named after the naked eye star δ Cephei. They are variables in their own right, unlike the eclipsing stars. It is not possible to draw a typical light curve, as considerable differences exist between different stars: particular shapes of light curve seem to be associated closely with definite periods. In general it may be said that the curve shows a sudden accession of brightness occupying only about a fifth of the period, followed by a slower decline and a relatively flat minimum. Periods are known from about one day (rarely) to about sixty days, and amplitudes up to 2½ magnitudes. It was early noticed that, of the many Cepheids visible in the Magellanic Clouds (and therefore at similar distances from us) the ones of longest period were also the brightest, and there was a definite relationship between period and luminosity. This period-luminosity law has been of the greatest value in determining the scale of the Universe (see **Stars, Distances and Motions**).

In the globular clusters of our Galaxy there are numerous Cepheid-like stars of remarkably short periods, almost all less than a day. These variables were originally known as *cluster Cepheids*, but examples were soon found outside clusters and the group is now named after one of these stars, RR Lyrae. Their light curves are generally similar to Cepheids, but there appears to be a marked break in characteristics between the two groups; very few stars of either type have periods of about one day, at which the break occurs.

Stars of both groups pulsate in the period of variation, alternately expanding and contracting. This does not in itself, however, account for the variation: the maximum light is accompanied by a higher surface tempera-

ture and an earlier spectral class. Spectra at maximum vary from class A for RR Lyrae stars to G for the Cepheids of longest period; at minimum they are about one class later.

SEMIREGULAR AND IRREGULAR VARIABLES. Unlike the foregoing, these do not have repetitive light curves. In semiregular variables a period is sometimes traceable; it is often about 100–200 days. In irregular variables the changes in brightness seem wholly capricious. Amplitudes are generally around two magnitudes. An interesting subgroup is that of RV Tauri. The light curve shows a period of about 80 days, involving two maxima and two unequal minima, superimposed on a slower oscillation of about four years.

LONG PERIOD VARIABLES. These are giant red stars with a characteristic period of about a year; only a few, mainly atypical, members of the group have periods outside the range 140 to 500 days. Amplitudes are large, commonly three to six magnitudes, with ϰ Cygni exceeding eight. The light curves show that deviations from the average of the order of a magnitude in amplitude and twenty days in period are commonplace. The extreme observed range of ϰ Cygni is well over ten magnitudes.

The brightest long period variable, o Ceti, occasionally reaches second magnitude. It aroused considerable interest in the 17th century before its periodic nature was recognized, and was given the name of Mira, meaning 'The Wonderful'. Long period variables are still sometimes known as Mira stars.

U GEMINORUM stars are small, faint stars which undergo outbursts at intervals, like recurrent small-scale novae. They have almost constant minima, then a sudden rise lasting only about 24 hours, followed by a slower decline. The decline may set in at once or the star may remain at maximum for ten days; such short and long maxima tend to follow each other alternately. Two stars, SU Ursae Majoris and AY Lyrae, have 'supermaxima' much longer and brighter than normal maxima. The mean interval between outbursts is generally between 14 and 100 days, UV Persei having an exceptional average of 270 days; but the interval is very variable and may range from half to twice the mean. Amplitudes increase with period from two and a half to five magnitudes. A sub-class with an additional peculiarity is named after Z Camelopardalis. The star has a period of about 23 days, but occasionally it stops its variation half-way down its decline and remains at constant brightness for months before resuming its normal variations. In 1948–50 a standstill lasted almost two years.

R CORONAE variables make up in peculiarity for what they lack in number. They remain at constant brightness much of the time (the type star did so for nine years in 1925–33) and then, in a few weeks, decrease in light by anything up to eight or nine magnitudes; there is then an irregular recovery lasting some months. Both the amount of the decline, and the interval between successive minima, is entirely random. As is the case in so many types of variation, the cause is still in doubt; but it seems to be external to the star itself as the spectrum remains singularly constant during the light changes. The stars contain much carbon, and a plausible theory suggests that condensation of carbon in their atmospheres may obscure their light at intervals.

Novae and **Supernovae** are discussed under their own headings. (R.G.)

VELOCITY is speed *in a given direction* although the word is often loosely used in the same sense as speed. Thus a car moving due North with a speed of 30 m.p.h. has northward, eastward and southward velocities of 30, 0, and —30 m.p.h. respectively.

VENUS is the second planet in order of distance from the Sun. It is considerably larger than Mercury or Mars, and has a much higher albedo (0.59), so that it appears brighter than any object in the sky apart from the Sun and Moon. The Magnitude at maximum brilliancy is —4.4, compared with —2.8 for Mars and only —1.8 for Mercury. Moreover, Venus may remain above the horizon for some hours after sunset, though owing to the extreme brightness of the disc the best observational work has been carried out during daylight.

THE CRESCENT VENUS photographed in blue light with the 200-inch telescope. There is a complete absence of markings, but the softness of the terminator indicates the presence of an atmosphere. (*Mount Wilson – Palomar*)

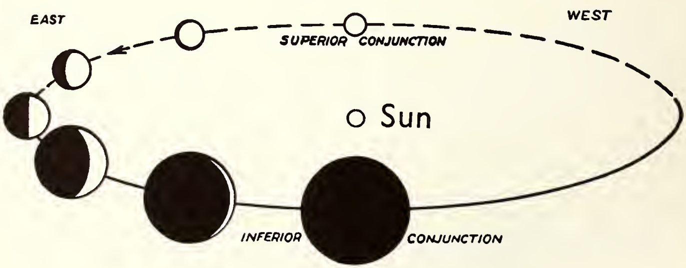
ORBIT. Venus has an orbital eccentricity of only 0.0068, which is less than that of any other planet. The almost circular orbit means that the distance from the Sun changes very little from its mean value of 67,200,000 miles; the perihelion and aphelion distances are 66,750,000 and 67,650,000 miles respectively. The orbital inclination of 3° 24′ means that transits across the Sun are very rare (see **Transits**). The sidereal period is 224 days 16 hours 48 minutes, and the mean orbital velocity is 31.7 miles per second.

PHASES. The phases of Venus were first detected by Galileo, and are obvious with any small telescope. Since Venus is comparatively remote when half or gibbous, it appears at maximum brilliancy during the crescent stage, 35 days after eastern elongation and 35 days before western elongation. The moment of exact half-phase is known as *dichotomy*. Owing to the presence of an atmosphere surrounding Venus, the times of theoretical and observed dichotomy may differ appreciably.

During the crescent phase, the unilluminated hemisphere of Venus is often faintly visible. The precise cause of this *Ashen Light* is uncertain. One theory attributes it to high-altitude aurorae in the atmosphere of the planet.

DIMENSIONS AND MASS. Venus has been described as the Earth's twin, and it is true that the two globes are remarkably similar in size and mass. Venus has a diameter of 7,700 miles, while the volume is 0.92 of that of the Earth and the mass 0.81. The density is 4.9 times that of water and the escape velocity 6.3 miles per second. These figures give a value for the surface gravity of 0.85 that of the Earth. Yet despite all this, Venus must be regarded as a non-identical twin, and from our point of view it is certain to prove decidedly hostile.

Below: THE PHASES OF VENUS. As the planet approaches the Earth, we see more and more of its unilluminated side, while its apparent size increases.



VENUS. Three 100-inch photographs showing irregularities in the edge of the terminator.
(*Mount Wilson – Palomar*)

ROTATION. The rotation period of Venus is not known with any accuracy. Schiaparelli supposed it to be equal to the sidereal period, as is the case with Mercury, but this is now considered unlikely in view of recent temperature measurements of the dark side. Spectroscopic research indicates that a very short period is improbable, and the best estimate is that Venus rotates in about a terrestrial month, so that there will be less than a dozen 'days' in the 'year'. However, the whole question remains completely open, and even the 225-day rotation period still has its adherents.

SURFACE FEATURES. Owing to the opaque atmosphere of Venus, the actual surface can never be observed even by means of infra-red techniques. We are confined to studies of the upper atmosphere, and the only features visible are vague bright and dusky patches. These patches are not permanent; they shift and alter in form from day to day, and seldom persist in recognizable form from one observation to the next, so that it is not possible to solve the problem of the rotation period by visual observation alone.

Bright areas are frequently seen to cover the cusps, and have been termed polar caps. There is however no analogy with the ice-caps of Earth or Mars, since the features on Venus are purely atmospheric. Moreover, it is not even certain that they mark the poles of rotation, since we have no definite knowledge as to the inclination of the axis. It is of course quite possible that the caps do lie over the true poles, in which case they are probably due to some peculiarity of the atmospheric circulation there, but this is merely a reasonable guess. The caps are not permanent, and their visibility cannot be predicted; they have been dismissed as contrast effects.

Less conspicuous bright patches can be seen elsewhere from time to time, but are nebulous and short-lived. The dusky shadings are equally indefinite, and though they can often be seen with a moderate telescope they are not easy to draw. Like the bright areas,

they must be due to phenomena in the upper atmosphere of Venus. The best photographs reveal definite shadings.

LINEAR FEATURES. Lowell observed Venus extensively between 1895 and 1916. He recorded sharp, permanent features, and even drew a map of the planet, while some more recent observers have described a 'wheel-spoke' system with streaks radiating from a central dark patch. These effects are much more likely to be purely optical, due largely to the brilliance of the disc.

ATMOSPHERE. Though Venus is surrounded by an extensive atmosphere, the composition differs markedly from that of our own air. Spectroscopic research has shown that there is an abundance of carbon dioxide, but an almost complete lack of water vapour and free oxygen. The amount of carbon dioxide appears to be 250 times as much per unit volume as that present in the Earth's atmosphere. Nitrogen may be present, but it is difficult to detect spectroscopically. It must of course be remembered that our investigations are confined to the upper layers, and we do not even know the precise depth of the atmosphere, though it is unlikely to be greater than a few hundreds of miles. Our information as to the composition of the 'clouds' is equally scanty.

ASHEN LIGHT. This is the name given to the faint luminosity of the night hemisphere of Venus, when that planet appears as a crescent. Various theories have been advanced to account for it (including one of the last century which attributed it to the glow from vast forest fires lighted by the inhabitants of Venus during religious festivals!), but it seems probable that the light is due to phenomena in the upper atmosphere of Venus, perhaps similar to our **aurorae**. It has been claimed that the Ashen Light is purely an effect of contrast, but recent observations do not support this idea, and it seems that the phenomenon is a real one.

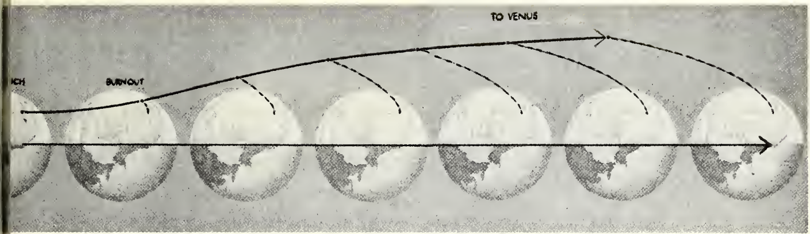
SURFACE CONDITIONS. Though Venus is the nearest of the planets, we know virtually nothing about the surface conditions. Observations of irregularities in the **terminator** led Schroeter, in 1790, to believe that the planet is mountainous, but though terminator irregularities can be seen from time to time it is far more logical to consider that they are due either to contrast or to atmospheric phenomena. There is no precise information as to the presence or absence of mountains on Venus.

Until fairly recently, Venus was thought to be a moist, steamy world similar to the Earth in Carboniferous times, with luxuriant vegetation and primitive life. Analysis of the atmosphere has led to the rejection of this theory, and there seem to be two reasonable alternatives. Either Venus is a monotonous dust-bowl, or else the surface is completely covered with water, as is suggested by Whipple and Menzel. In either case, the abundance of atmospheric carbon dioxide means that the temperature is likely to be unpleasantly high.

NON-EXISTENCE OF A SATELLITE. Like Mercury, Venus has no known satellite. If Venus has a minor attendant, it can hardly be more than a mile or two in diameter.

VENUS AS A RADIO SOURCE. In 1956, radio noise originating on Venus was detected by astronomers working independently at Ohio and at Washington. At Washington, radiation with a wavelength of 3.15 centimetres was observed for the first time in May 1956, and this has provided support for the theory that the surface temperature of the planet is very high, though the conclusions must for the moment be tentative. Fluctuating bursts of radio noise from Venus observed from Ohio have been compared with the static from terrestrial thunderstorms. Periodicity in the 'static' from Venus may eventually provide reliable information with regard to the length of the rotation period.

POSSIBILITY OF LIFE. Probably advanced life as we know it cannot exist upon Venus. If we accept the marine theory of Whipple and Menzel, it is just within the bounds of possibility that primitive organisms may flourish in the waters. Probably the first expeditions from Earth will not land, but will circle above the atmosphere in an attempt to gain some definite information as to conditions below. All we know at the moment is that Venus is unlikely to extend us a friendly welcome. (P.M.)

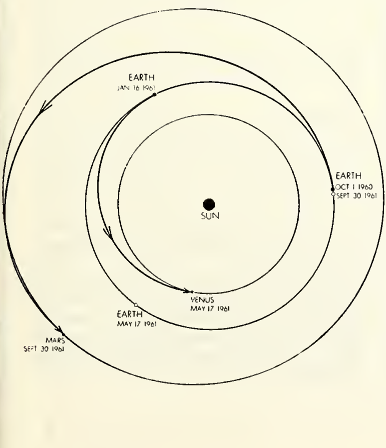


TRAJECTORY OF A VENUS PROBE. The Earth is shown viewed from high above the North Pole an intervals of eight minutes. The solid line indicates the path of the probe as seen from this position. To as observer at the launching point it would appear as shown by the broken line. The direction of the Sun it towards the top of the page.

VENUS PROBE. A Sun satellite designed for the preliminary exploration of conditions in space near **Venus.**

The first Venus probe, *Pioneer V*, was launched by the U.S.A. on March 11, 1960. Its orbit relative to the Earth and to the Sun is shown in the diagram above. Closest approach to Venus occurs 151 days after launching, when the probe will be within 7 million miles of the planet. During most of its course the probe is outside tracking and radio reception from the Earth, and it therefore stores information for transmission when it is within range. Its transmitters are switched on and off by signals from the Jodrell Bank radio telescope.

The firing of a Venus probe must be in a direction against that of the Earth's orbital motion round the Sun so that the probe can gravitate inwards by virtue of its reduced orbital velocity relative to the Sun. Details of the orbit of the *Pioneer V* probe are given in the tabulation under **Artificial Satellite.**



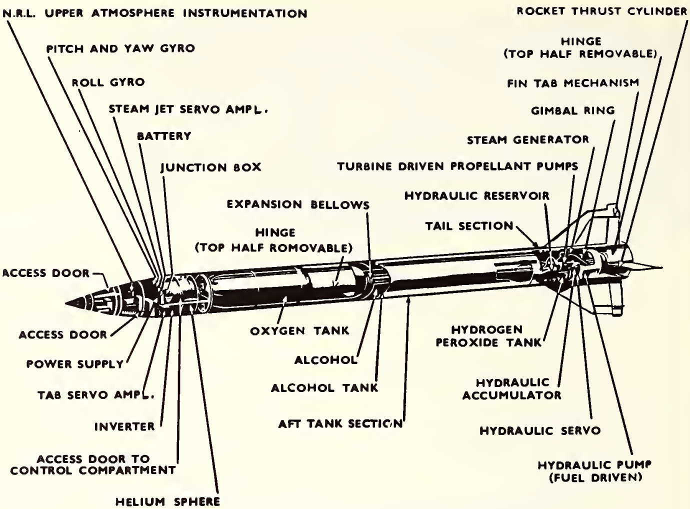
VERNAL EQUINOX. The time when the Sun appears to cross the celestial equator in a northerly direction, about March 21 each year. See **Equinox** and **Celestial Sphere.**

VERONIQUE. A French high-altitude research rocket.

VESTA. Although it has a diameter of only 214 miles, much less than that of Ceres or Pallas, Vesta is the brightest of the **asteroids.** It can reach almost 6th magnitude, and so can be glimpsed without optical aid. It has a period of 3.63 years, and was the fourth member of the swarm to be discovered (1807).

VIKING. A series of high altitude research rockets made in the U.S.A. since 1949. Much pioneer work was carried out by Viking rockets, which were developed in the U.S.A. from the German **A-4** (V-2) missile after the Second World War. A diagram is given on the next page.

VULCAN. The name that was proposed for the non-existent **Intra-Mercurian Planet.**



CUT-AWAY DIAGRAM OF A VIKING ROCKET.

NOSE CONE UNDER HEAT TEST. The nose cone is being exposed to the searing heat from 225 quartz-tube lamps. Tests such as this are supplementary to wind tunnel experiments.
(*N.A.S.A.*)

W

WAC CORPORAL. An American high-altitude research rocket.

WARGENTIN. One of the most unusual lunar craters; it appears 'full to the brim'.

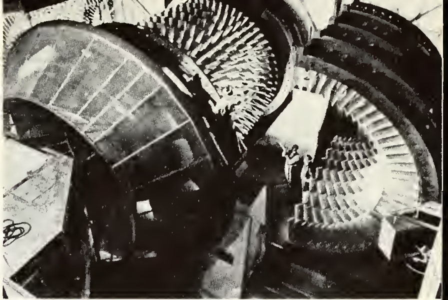
WARHEAD. The explosive nose compartment of a missile.

WEIGHT. The force of attraction of a gravitating body upon a mass. See **Gravitation.**

WHITE DWARF. A star consisting of **degenerate matter.** A white dwarf is small and immensely dense – 100,000 or 1,000,000 times as dense as water. It has no nuclear energy source. See **Hertzsprung-Russell Diagram.**

WILSON CLOUD CHAMBER

Right: WIND TUNNEL compressor blades at Cleveland, Ohio. They are driven by three electric motors with a total horsepower of 260,000 and send a stream of air at supersonic speed through the six-by-eight-foot tunnel.



WILSON CLOUD CHAMBER. The first detector of charged sub-atomic particles. It consists of a cylinder fitted with a movable piston, at least part of the cylinder being transparent. The space above the cylinder contains air saturated with water vapour; if the piston is suddenly withdrawn a little way some of the vapour condenses as tiny droplets If, at the critical moment, a charged particle enters, it leaves a trail of ionized molecules, and the vapour condenses more easily upon the ions than elsewhere. Consequently a particle leaves a trail of small water droplets which mark its path and allow the latter to be photographed.

WIND TUNNEL. A long, narrow chamber in which models and prototypes can be exposed to high velocity air streams to test their aerodynamic and thermal characteristics. See **Air Resistance**.

WINDOWS, ATMOSPHERIC. See **Atmosphere of the Earth.**

WOLF-RAYET STAR. A star of a class related to the early main sequence stars. The hottest main sequence stars, those of types O and early B, tend to show bright emission lines in their spectra. These are known as *shell stars*. In extreme cases the spectra consist almost entirely of bright lines: such stars are placed in Class W, the *Wolf-Rayet* stars. Their bright lines are usually very broad and hazy, and it used to be thought that matter was streaming from their surfaces with high velocity, causing great Doppler broadening of the lines. The spectra certainly come from gaseous envelopes at extreme temperature, but matter does not seem to be rapidly lost from these. Ionized helium, and highly ionized carbon, nitrogen and oxygen, are present in the envelopes. Recently many of the Wolf-Rayet stars have been discovered to be spectroscopic binaries, and an appraisal of the dimensions of both envelopes and stars should soon be possible.

X

X-15. One of the latest of a series of high-altitude rocket planes designed to take a pilot to the fringes of space. It is carried to 40,000 feet by a conventional aircraft; its rocket motor fires for ninety seconds after it is released, and takes it to a height of 100 miles or over a horizontal range of almost 500 miles at 3,600 m.p.h. It returns to the ground by gliding.

NORTH AMERICAN X-15 ON THE GROUND.

Y

YEAR. Several measurements of the year are recognized, and each gives a different length. They are enumerated below and their lengths in mean solar days (civil days) are tabulated for epoch 1960.

Tropical Year is the time between successive vernal equinoxes. This keeps in step with the seasons, and the civil year of the Gregorian calendar is based on it. Owing to precession, the equinoxes regress round the ecliptic about 50 seconds of arc per year, making a whole revolution in 26,000 years; consequently the tropical year is shorter by about one part in 26,000 than the

Sidereal Year, which is the 'true' year or the time taken by the Earth to traverse its orbit once and return to the same direction in space relative to the Sun.

Eclipse Year is the length of time between successive returns of the Sun to the Moon's ascending node. If the Moon's orbit were fixed in space the eclipse year would be equal to the sidereal; but the Moon's nodes regress rapidly round the ecliptic, completing a revolution in about 18 years, causing the eclipse year to be much shorter than the other years. The eclipse year is so named because it is the interval between eclipses, which can only take place near a node.

Besselian Fictitious Year begins at the instant when the Sun's mean longitude is 280°; this occurs on December 31 or January 1 each calendar year. The Sun's longitude at this time is 80° less than at the vernal equinox, and therefore the beginning of the Besselian year simply marks a particular time in the tropical year.

Gregorian Year is the mean length of year on the Gregorian calendar, and

Julian Year the mean length on the Julian calendar.

The yearly course of the seasons is a result of the inclination of the Earth's axis to the plane of its orbit. The axis maintains a fixed direction in space, so that the northern hemisphere is tilted towards the Sun in summer and away from it in winter. This applies in varying degrees to the other planets; the length of their years increases with mean distance from the Sun.

Year	*Mean Solar Days*	d	h	m	s
Tropical	365.242195	365	5	48	45
Sidereal	365.256360	365	6	9	10
Anomalistic	365.259643	365	6	13	53
Eclipse	346.620050	346	14	52	52
Gregorian	365.2425	365	5	49	12
Julian	365.25	365	6		

Anomalistic Year is the mean interval between succeeding perihelia in the Earth's motion. The position of perihelion progresses round the Earth's orbit by an average of 11 seconds of arc per year, making the anomalistic year slightly longer than the sidereal year.

Z

ZEEMAN EFFECT. The phenomenon of the splitting of spectral lines formed in a magnetic field, which was predicted, before its discovery, by Zeeman in 1896.

Magnetic fields have been detected upon the Sun and some stars by observing the Zeeman effect. The **magnetograph** enables separations of the lines which are very small compared with the widths of the lines themselves to be measured with accuracy, with the aid of special filters.

If a star has a magnetic field and no filters are used when its spectrum is photographed, the components of each line merge together; the overall effect is to broaden the lines.

ZENITH. The point on the **celestial sphere** vertically above the observer.

ZENITHAL ATTRACTION. The apparent 'lifting' of a star's altitude owing to refraction in the Earth's atmosphere (see **Altitude**).

Altitude (*degrees*)	*Zenithal Attraction* (N.T.P.)
0	36′
5	10′.3
10	5′.4
20	2′.7
30	1′.8
50	0′.9
90	0

ZERO, ABSOLUTE. See **Absolute Zero.**

ZERO GRAVITY. The state of **free fall**, or the total force acting at a point where gravitation and *all other* accelerations cancel out. Zero gravity has nothing to do with distance from the centre of any gravitational attraction, since the gravitational field of any body, no matter how small, extends infinitely far in all directions.

ZENITH DISTANCE. The angle between a star, the observer and his **zenith.**

ZODIAC. The belt of sky lying within eight or ten degrees of the **ecliptic**, within which the Sun, Moon and most of the planets appear to travel. Starting from the **First Point of Aries**, it is divided into twelve *Signs of the Zodiac*, each represented by a symbol and a character (usually an animal). There are twelve *Zodiacal Constellations* which have the same names as the signs but do no longer coincide with them. Since the naming of the First Point of Aries 2,300 years ago, precession has carried the signs westward 30°, or a whole sign, with respect to the constellations.

The Signs of the Zodiac played an important part in Astrology, and were studied with great care. We owe the existence and preservation of many astronomical records of the greatest antiquity to this otherwise pernicious and baseless superstition.

ZODIACAL CLOUD. The cloud of meteoric bodies responsible for the **Zodiacal Light.**

ZODIACAL LIGHT. This is a faintly luminous band extending along the whole length of the **ecliptic.** The brightest part is nearest the Sun; another, but much fainter, maximum occurs in the direction diametrically opposite to the Sun. This secondary maximum is named the *Gegenschein* or Counterglow. In temperate latitudes only the part of the Light near the Sun is often seen: it appears as a diffuse luminous area extending along the ecliptic from the position of the Sun, being widest and brightest near the horizon and becoming narrower and fainter away from the Sun. The most favourable times for observation are clear, moonless nights, after dusk in spring and before dawn in autumn. The advantage of these times is that the ecliptic then intersects the horizon at a steep angle, and parts of it quite close to the Sun are therefore observable when the Sun is sufficiently below the horizon to give a dark sky. In the tropics the ecliptic always makes a large angle with the horizon, and the Zodiacal Light is often quite conspicuous. (Exactly similar considerations apply to the visibility

of the planet Mercury, which can never appear more than 28° from the Sun.)

The spectrum of the Zodiacal Light shows it to be reflected sunlight. It seems probable that the reflection takes place from myriads of meteoric bodies with dimensions of the order of inches or feet, which form a lens-shaped cloud round the Sun in the plane of the ecliptic. The cloud extends beyond the Earth's orbit, so that some of the bodies exist in all directions in the plane of the ecliptic but most lie in the directions close to the Sun. The bodies are too small to be seen individually, but their integrated light accounts for the diffuse glow seen from the Earth. (R.G.)

ZONE TIME. See **Standard Time.**

THE ZODIACAL LIGHT, from a painting by E. L. Trouvelot.

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